M&V Guidelines:
Measurement and Verification for Federal Energy Projects

Version 3.0

U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

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Measurement and Verification for Federal Energy Projects
Version 3.0

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1.1 OVERVIEW AND PURPOSE OF THE FEDERAL ENERGY MANAGEMENT PROGRAM (FEMP) M&V GUIDE

This document provides guidelines and methods for measuring and verifying energy, water, and cost savings associated with federal energy savings performance contracts (ESPCs). An ESPC is a contracting method in which the contractor provides and arranges financing and implementation of energy improvements and is repaid over the contract term from the cost savings generated by the improvements.

1.1.1 The Federal ESPC Authority

The federal use of ESPCs was authorized in the 1986 amendments to the National Energy Conservation Policy Act of 1978 (NECPA), which gave federal agencies the authority to enter into shared-energy-savings contracts with private-sector energy service companies (ESCOs). The Energy Policy Act of 1992 (EPACT) further amended NECPA, authorizing federal agencies to execute guaranteed-savings ESPCs. EPACT also directed DOE to develop an ESPC regulation through a formal rule-making process. The final ESPC rule was published on April 10, 1995 and implemented the DOE ESPC regulation at 10 CRF Part 436 Subpart B. The Ronald W. Reagan National Defense Authorization Act for FY 2005 revised the definition of energy savings in federal ESPCs to include water conservation measures, and the National Energy Independence and Security Act of 2007 extended the federal ESPC authority indefinitely.

Some aspects of the legislation are related to measurement and verification of savings. These items include requirements for measurement and verification of savings, annual energy audits, and factors that adjustments can be made for.

Current federal energy goals are defined in Executive Order 13423, released in January 2007, which strongly supports the use of alternative financing methods, including ESPCs, to achieve them.

For more information about federal ESPCs, including the authorizing legislation, regulations, and all aspects of implementing ESPC projects, go to the website of the FEMP, http://www1.eere.energy.gov/femp/financing/superespcs_espcrule.html.

1.1.2 The Financial Structure of ESPCs

In an ESPC, the ESCO provides the energy surveys, engineering, design, construction management, labor, equipment, and sometimes maintenance to reduce energy and water use and costs, as well as related costs such as operations and maintenance (O&M) of energy systems. In federal ESPCs, the ESCO is required to guarantee a specific level of cost savings that will be sufficient to pay for the improvements over the term of the contract. Savings must exceed payments in every year of the contract. The federal ESPC authority requires the contractor to undertake measurement and verification (M&V) activities and provide documentation to demonstrate that the guarantee has been met.

As shown in Figure 1-1, ESPCs reallocate the money the agency pays for utilities. Energy costs are reduced, and part of the savings are paid to the ESCO for the improvements that generate the savings. The energy savings realized through an ESPC project provide the income stream to finance the project. After the contract term ends, any additional savings will accrue to the agency.

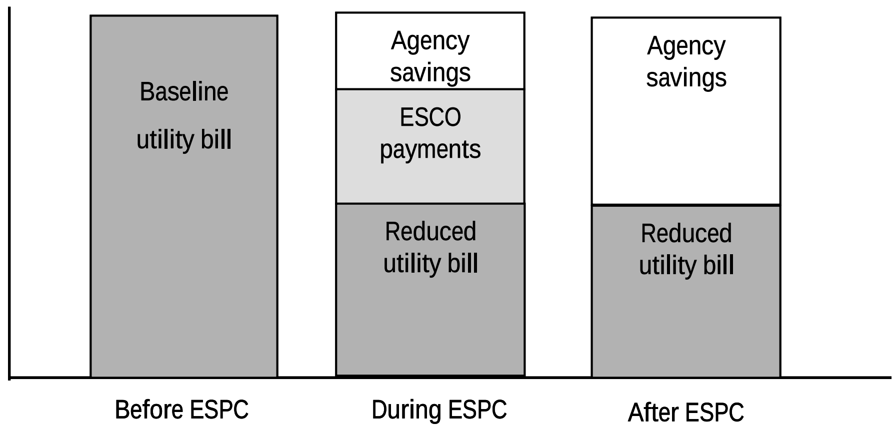

Figure 1-1 ESPC Reallocation of Money Paid for Utilities

An ESPC can be used to finance renewable energy systems, water conservation, related O&M improvements, and other measures, as well as energy conservation measures and energy-efficient systems. Thus, in this document the word "energy" is used as a generic term that includes other things besides traditional sources of heat and electric power. The contract can apply to both new construction and retrofits. In many cases, old, inefficient equipment is replaced with new equipment and control systems.

1.1.3 Purpose of the FEMP M&V Guide

This document contains procedures and guidelines for quantifying the savings resulting from energy efficiency equipment, water conservation, improved operation and maintenance, renewable energy, and cogeneration projects implemented through ESPCs. This document is intended for federal energy managers, federal procurement officers, and contractors implementing performance contracts at federal facilities.

The DOE Super ESPCs include a contractual requirement for ESCOs to comply with this guide in planning and carrying out M&V activities for federal agency customers.

The "performance" aspect of performance contracting refers to energy performance and drives the way in which savings are determined. Since the M&V approach calculates and documents energy savings, it is one of the most important activities associated with implementing performance contracts and is a crucial issue in contract negotiations.

This document has two primary purposes:

- It serves as a reference document for specifying M&V methods and procedures in delivery orders, requests for proposals (RFPs), and performance contracts.

- It is a resource for those developing project-specific M&V plans for federal ESPC projects, especially under DOE's Super ESPC contract mechanism.

The procedures defined in this document 1) can be applied with consistency to similar projects throughout all geographic regions, and 2) are impartial, reliable, and repeatable. If the procedures in this document are followed by a federal agency or other entity, then that agency or entity can be assured that their guaranteed savings can be realized.

1.1.4 Overview

The first three chapters of this Guideline present an overview of the M&V process and issues related to responsibility allocation, thereby providing the context for the specific M&V requirements that are essential in a federal ESPC project. Chapter 4 presents details of the four general M&V methods that should be used. Chapter 5 offers guidance on selecting an M&V approach for specific projects, and Chapter 6 details the M&V related submittals that are required in a Super ESPC project. Chapters 7, 8, and 9 discusses important issues that must be considered and specified in the contract, including M&V Plan details, commissioning requirements, and O&M responsibilities. Chapter 10 covers the key oversight issues that are the responsibility of the government. Chapter 11 includes guidance on determining savings from the most common technologies included in federal ESPCs.

The Appendices to this document are fairly large, and are provided as a separate PDF document. Items include a definition of terms; guidance on statistical sampling; as well as instructions, formats, and checklists for reviewing M&V submittals. Several items developed by government-industry working groups are also provided, including standard M&V Plan templates for both lighting retrofits and chiller replacements, guidance on verifying O&M savings, and the M&V Plan and reporting outlines. The final appendix includes guidance on incorporating retro-commissioning services in performance contracts. Additional materials developed for the Super ESPC program are available online[1], including the M&V Plan and reports from a fictitious project.

This is Version 3.0 (2008) of the Guideline. Version 2.2 was published in 2000; Version 2.0 was published in 1996. This new version incorporates significant updates to the 2000 version. Much of the guidance included was developed by a variety of industry-government working groups, facilitated by DOE, since the release of the previous version. Some of the material developed has been incorporated in the Super ESPC contract. In developing the present version, the entities involved:

- Updated terminology and processes to harmonize with the 2008 Super ESPC master contract
- Updated definitions of savings and adjustments to match IPMVP 2007
- Revised Option A strategies to be in line with IPMVP 2007, noting when exceptions can be made
- Eliminated several measure-specific approaches and added a discussion on key issues related to the most common energy conservation measures (ECMs)

[1] Additional Super ESPC materials related to measurement and verification of savings are available at http://www1.eere.energy.gov/femp/financing/superespcs_mvresources.html and http://ateam.lbl.gov/mv/.

- Added significant information on planning for operations and maintenance in ESPCs
- Provided details and example on verifying energy related cost saving from operations and maintenance
- Added detailed formats for M&V plans and reports
- Added an example of an M&V Plan and reports for a fictitious Super ESPC project
- Included FEMP's Standard M&V Plan for Lighting Replacements

1.2 OTHER M&V GUIDELINES

Measuring and verifying savings from performance contracting projects requires special project planning and engineering activities. Although M&V is an evolving science, industry best practices have been developed. These practices are documented in several guidelines, including the International Performance Measurement and Verification Protocol[2] (IPMVP 2007) and ASHRAE Guideline 14: Measurement of Energy and Demand Savings[3] (2002). These two guidelines are described below.

1.2.1 IPMVP

The IPMVP 2007 is a guidance document that provides a conceptual framework in measuring, computing, and reporting savings achieved by energy or water efficiency projects at facilities. The IPMVP defines key terms and outlines issues that must be considered in developing an M&V Plan, but does not provide details for specific measures or technologies. The latest version is an update of the 2002 edition.

Developed through a collaborative effort involving industry, government, financial, and other organizations, the IPMVP serves as the framework for M&V procedures, provides four M&V options, and addresses issues related to the use of M&V in third-party-financed and utility projects.

The FEMP M&V Guideline contains specific procedures for applying concepts originating in the IPMVP. The Guideline represents a specific application of the IPMVP for federal projects. It outlines procedures for determining M&V approaches, evaluating M&V plans and reports, and establishing the basis of payment for energy savings during the contract. These procedures are intended to be fully compatible and consistent with the IPMVP.

1.2.2 ASHRAE Guideline 14

ASHRAE Guideline14-2002 Measurement of Energy and Demand Savings is a reference for calculating energy and demand savings associated with performance contracts using measurements. In addition, it sets forth instrumentation and data management guidelines and describes methods for accounting for uncertainty associated with models and measurements. Guideline 14 does not discuss other issues related to performance contracting.

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2 *International Performance Measurement and Verification Protocol: Concepts and Options for Determining Energy and Water Savings Volume I*, EVO-10000 -1.2007, Efficiency Valuation Organization.

3 *ASHRAE Guideline 14-2002: Measurement of Energy and Demand Savings*, American Society of Heating, Refrigerating and Air-Conditioning Engineers.

The ASHRAE document specifies three engineering approaches to M&V. Compliance of each approach requires that the overall uncertainty of the savings estimates is below prescribed thresholds. The three approaches presented are closely related to and support the options provided in IPMVP.

Implementing measurement and verification (M&V) strategies in energy performance contracts is required in federal contracts such as the Super Energy Savings Performance Contracts (Super ESPCs). Since energy savings are guaranteed, the legislation requires that the contractor verify that energy cost savings have been achieved each year.

The federal legislation outlining the rules for implementing federal ESPC projects is the Energy Policy Act of 1992 (EPACT). The EPACT legislation includes specific requirements for annual verification of energy cost savings to support the saving guarantee. The goal of measurement and verification is to reduce the risk to agencies by providing a mechanism to evaluate the performance of a project throughout the term of the contract. The savings guarantee is defined by the M&V activities, whose function is to reduce agency risk. The challenge of M&V is to balance M&V costs with the value of increased certainty in the cost savings from the conservation measure.

Many of the reasons for using M&V strategies go beyond merely satisfying the law. Properly applied, M&V can:

- Accurately assess energy savings for a project
- Allocate risks to the appropriate parties
- Reduce uncertainties to reasonable levels
- Monitor equipment performance
- Find additional savings
- Improve operations and maintenance (O&M)
- Verify that the cost savings guarantee is met
- Allow for future adjustments, as needed

2.1 GENERAL APPROACH TO M&V

Facility energy (O&M or water) savings cannot be measured, since they represent the absence of energy use. Instead, savings are determined by comparing the energy use before and after the installation of conservation measure(s), making appropriate adjustments for changes in conditions.

The “before” case is called the baseline. The “after” case is referred to as the post-installation or performance period. Proper determination of savings includes adjusting for changes that affect energy use, but that are not caused by the conservation measure(s). Such adjustments may account for changes in weather, occupancy, or other factors between the baseline and performance periods. Equation 2-1 shows the general equation used to calculate savings.

Equation 2-1: General Equation Used to Calculate Savings

$$Savings = (Baseline \quad Energy - Post \quad Installation \quad Energy) \pm Adjustments$$

Baseline and performance period energy use can be determined by using the methods associated with several different M&V approaches classified by the types of measurements performed. The four options, originating in the International Performance Measurement and Verification Protocol (IPMVP), are termed Options A (Retrofit Isolation with Key Parameter Measurement), B (Retrofit Isolation with All Parameter Measurement), C (Whole Building), and D (Calibrated Simulation). (These options are discussed in Chapter 4 of this document.) These options enables one to apply a range of suitable techniques for a variety of applications. How one chooses and tailors a specific option is determined by the level of M&V rigor required to obtain the desired accuracy level in the savings determination and is dependent on the complexity of the conservation measure, the potential for changes in performance, the measure's savings value, and the project's allocation of risk.

Two fundamental factors drive energy savings: performance and usage. Performance describes how much energy is used to accomplish a specific task; usage describes how much of the task is required, such as the number of operating hours during which a piece of equipment operates. For example, in the simple case of lighting, performance is the power required to provide a specific amount of light, and usage is the operating hours per year. For a chiller (which is a more complex system), performance is defined as the energy required to provide a specific amount of cooling (which varies with load), whereas usage is defined by the cooling load profile and the total amount of cooling required. Both performance and usage factors need to be known to determine savings, as shown in Figure 2-1.

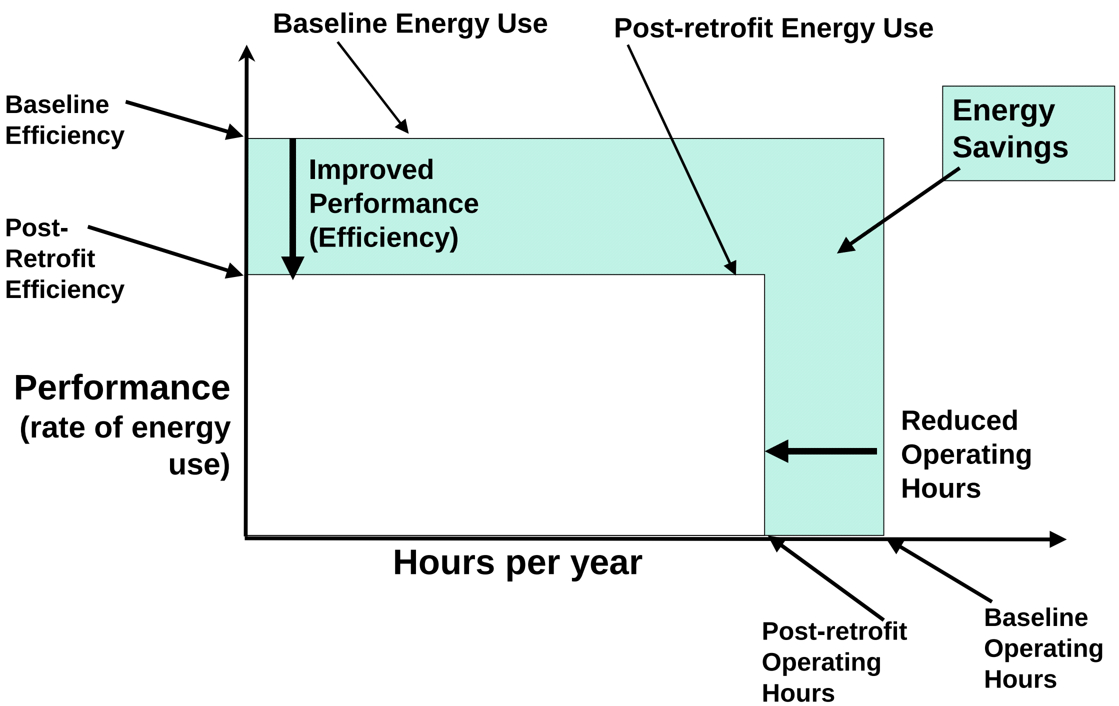

Figure 2-1 Energy Savings Depend on Performance and Usage

In Figure 2-1, the area of the large box represents the total energy used in the baseline case. Reduction in the rate of energy use (increase in performance) or reductions in usage (decrease in operating hours) lead to reduced total energy use, which is represented by the smaller box. The difference between the two boxes—the shaded area—represents the energy savings.

M&V activities include site surveys, metering of energy and independent variables, engineering calculations, and reporting. How these activities are applied to determine energy savings depends on the characteristics of the energy conservation measures (ECMs) being implemented and balancing accuracy in energy savings estimates with the cost of conducting M&V.

2.2 STEPS TO DETERMINE AND VERIFY SAVINGS

In general, determining actual savings achieved can be difficult and costly. In many performance contracts, it is more important to verify the potential of the ECM to generate the predicted savings. Verifying the potential to perform requires confirming that:

- The baseline conditions were accurately defined
- The proper equipment/systems were installed and properly commissioned
- The equipment/systems are performing to specification

Although confirming these items may appear simple, a structured approach is helpful. Regardless of the M&V option used, similar steps are taken to verify and determine the project's performance. These steps are outlined in Table 2-1, and an overview of each one is included in this section.

Table 2-1 Steps to Verify Savings from Performance Contracts

Timing		Activity
Before Project Implementation	Step 1	Allocate project responsibilities
	Step 2	Develop a project-specific M&V plan
	Step 3	Define the baseline
During Project Implementation	Step 4	Install and commission equipment and systems
	Step 5	Conduct post-installation verification activities
After Project Implementation	Step 6	Perform regular-interval verification activities during the performance period

The sections below provide an overview of M&V activities in each phase of the ESPC project. Additional details on these topics are included in later sections.

2.2.1 Step 1: Allocate Project Responsibilities

The basis of any project-specific M&V Plan is determined by the allocation of key project responsibilities between the energy service company (ESCO) and the federal agency involved. On an ESPC project, a number of typical financial, operational, and performance issues must be considered when allocating risks and responsibilities. These issues are discussed in Chapter 3. The distribution of responsibilities will depend on the agency's resources and preferences, and the ESCO's ability to control certain factors.

2.2.2 Step 2: Develop a Project-Specific M&V Plan

The M&V Plan is the single most important item in an energy savings guarantee. The plan defines how savings will be calculated and specifies any ongoing activities that will occur during the contract term.

Although the M&V Plan is usually developed during contract negotiations, it is important that the agency and the ESCO agree upon general M&V approaches to be used prior to starting the Investment Grade Audit (IGA). The M&V method(s) chosen will determine to a large extent what activities are conducted during the audit, and will affect the cost and duration of the audit.

The project-specific M&V Plan includes project-wide items as well as details for each ECM.

Project-wide items include:

- Overview of proposed energy and cost savings
- Schedule for all M&V activities
- Agency witnessing requirements
- Utility rates and the method used to calculate cost savings
- O&M reporting responsibilities

ECM-level items include:

- Details of baseline conditions and data collected
- Documentation of all assumptions and sources of data

- Details of engineering analysis performed
- The way energy savings will be calculated
- Details of any O&M or other cost savings claimed
- Details of proposed energy and cost savings
- Details of post-installation verification activities, including inspections, measurements, and analysis
- Details of any anticipated routine adjustments to baseline or reporting period energy
- Content and format of all M&V reports (post-installation and periodic M&V)

2.2.3 Step 3: Define the Baseline

Typically, the ESCO defines the baseline as part of the IGA. Baseline physical conditions (such as equipment inventory and conditions, occupancy schedule, nameplate data, equipment operating schedules, energy consumption rate, current weather data and control strategies) are determined during the IGA through surveys, inspections, spot measurements, and short-term metering activities. Utility bills are often used to verify the baseline has been accurately defined. Baseline conditions are established for the purpose of estimating savings by comparing the baseline energy use with the post-installation energy use. Baseline information is also used to account for any changes that may occur during the performance period, which may require baseline energy use adjustments. This baseline information is included in the ESCO's Final Proposal. It is the agency's responsibility to ensure that the baseline has been properly defined. If a whole building metering or calibrated simulation approach is used, it is important to document the baseline energy use of all end uses, not just those affected by the retrofit.

After the ECM has been implemented, one cannot go back and reevaluate the baseline. It no longer exists! Therefore, it is very important to properly define and document the baseline conditions. Deciding what needs to be monitored (and for how long) depends on such factors as the complexity of the measure and the stability of the baseline, including the variability of equipment loads and operating hours, and the other variables that affect the load.

The primary sources of questions and complaints on Super ESPC projects are the occasional situations where the customer does not think that savings are being realized. Adequate documentation of the baseline is critical to resolving any such disagreements that may arise.

2.2.4 Step 4: Install and Commission Equipment and Systems

Commissioning of installed equipment and systems is considered industry best-practice and is required on Super ESPC projects. Commissioning ensures that systems are designed, installed, functionally tested in all modes of operation, and are capable of being operated and maintained in conformity with the design intent (appropriate lighting levels, cooling capacity, comfortable temperatures, etc.). Commissioning is generally completed by the ESCO and witnessed by the agency. In some cases, however, it is contracted out to a third party.

Commissioning activities include inspections and functional testing. These activities are specified in a Commissioning Plan, and their results are documented in a Commissioning Report. More specific information on commissioning for ESPC projects is provided in Section 8.

Commissioning usually requires performance measurements to ensure that systems are working properly. Because of the overlap in commissioning and post-installation M&V activities, some people may confuse the two. The difference is that commissioning ensures that systems are functioning properly, whereas post-installation M&V quantifies how well the systems are working from an energy standpoint.

2.2.5 Step 5: Conduct Post-Installation Verification Activities

Post-installation measurement and verification activities are conducted by both the ESCO and the federal agency to ensure that proper equipment/systems were installed, are operating correctly, and have the potential to generate the predicted savings. Verification methods include surveys, inspections, spot measurements, and short-term metering.

The Post-Installation Report includes:

- Project description
- Detailed list of installed equipment
- Details of any changes between the Final Proposal and as-built conditions, including any changes to the estimated energy savings
- Documentation of all post-installation verification activities and performance measurements conducted
- Performance verification—how performance criteria were met
- Documentation of construction-period savings (if any)
- Status of rebates or incentives (if any)
- Expected savings for the first year

For projects using certain M&V methods (Option A)(see Chapter 4), the post-installation verification is the most important M&V step, because any measurements to substantiate the savings guarantee are made only once. For some measures, where equipment performance and energy savings are not expected to vary significantly over time, post-installation measurements may be the primary source of data used in the savings calculations.. Thereafter, inspections are conducted to verify that the potential to perform exists.

2.2.6 Step 6: Perform Regular-Interval Verification Activities

At least once a year, the ESCO and the federal agency are required to audit the project. This includes, at a minimum, verifying that the installed equipment/systems have been properly maintained, continue to operate correctly, and continue to have the potential to generate the predicted savings.

An Annual Report from the ESCO is required to document annual M&V activities and report verified and guaranteed savings for the year. In many cases, however, more frequent verification activities are appropriate. More frequent monitoring and/or inspection ensures that the M&V monitoring and reporting systems are working properly, installed equipment and systems are operating as intended throughout the year, allows fine-tuning of measures throughout the year based on operational feedback, and it avoids surprises at the end of the year.

The Annual Reports must include:

- Results/documentation of performance measurements and inspections
- Verified savings for the year (energy, energy costs, O&M costs, etc.)
- Comparison of verified savings with the guaranteed amounts
- Details of all analysis and savings calculations, including commodity rates used and any baseline adjustments performed
- Summary of operations and maintenance activities conducted
- Details of any performance or O&M issues that require attention

3.1 USING M&V TO MANAGE RISK

DOE's overarching energy savings performance contract, Super ESPC, establishes general terms and conditions of the agreement between the agency and the energy service company (ESCO). On individual projects (Task Orders) there is broad latitude to tailor a deal to suit the federal agency's own particular needs, priorities, and circumstances. At the heart of a performance contract is a guarantee of a specified level of cost savings and performance. One of the primary purposes of measurement and verification (M&V) is to reduce the risk of non-performance to an acceptable level, which is a subjective judgment based on the agency's priorities and preferences. In performance contracts, project risks and responsibilities are allocated between the ESCO and the owner. In the context of M&V, the word "risk" refers to the uncertainty that expected savings will be realized, including the potential monetary consequences.

The allocation of responsibilities between the ESCO and the agency drives the measurement and verification strategy, which actually defines the specifics of how fulfillment of the savings guarantee will be determined. Both ESCOs and agencies are reluctant to assume responsibility for factors they cannot control.

A few fundamental principles can be applied to the allocation of responsibilities in Super ESPC agreements:

- Logic and cost-effectiveness drive the allocation of responsibilities.
- The responsible party predicts its likely tasks and associated costs to fulfill its responsibilities, and makes sure these are covered in the ESPC or the agency's budget.
- Any unforeseen costs are paid by the party that caused the costs, or by the party responsible for that risk area.
- Stipulating certain parameters in the M&V Plan can align responsibilities, especially for the items no one controls.

The risks in achieving energy savings can be allocated to usage and performance factors.

Risk related to usage stems from uncertainty in operational factors. For example, savings fluctuate depending on weather, the number of hours in which equipment is used, user intervention, and equipment loads. Because ESCOs often have no control over such factors, they are usually reluctant to assume usage risk. The agency generally assumes responsibility for usage risk by either allowing baseline adjustments based on measurements or by agreeing to stipulated equipment operating hours, cooling load profiles, or other usage-related factors.

Performance risk is the uncertainty associated with characterizing a specified level of equipment performance. The ESCO is ultimately responsible for selection, application, design, installation, and performance of the equipment, and typically assumes responsibility for achieving savings related to equipment performance. Operations, preventive maintenance, and repair and replacement practices can have a dramatic impact on equipment performance. These responsibilities must be carefully planned, and are discussed in further detail in Chapter 8 of this document.

Stipulating certain parameters in the M&V Plan can align responsibilities, especially for the items that no one controls. Using stipulations means that the ESCO and agency agree to employ a set value for a parameter throughout the term of the contract, regardless of the actual behavior of that parameter.

If no stipulated values are used and savings are verified based entirely on measurements, then all risk resides with the ESCO, which must show that the guaranteed savings are realized, regardless of contributing factors. Alternatively, the agency assumes the risk for the parameters that are stipulated. In the event that the stipulated values overstate the savings, or reductions in use decrease the savings, the agency must still pay the ESCO for the agreed-upon savings. If the actual savings are greater than expected, the agency retains all of the surplus savings.

The use of stipulations can be a practical, cost-effective way to reduce M&V costs and allocate risks. Stipulations used appropriately do not jeopardize the savings guarantee, the agency's ability to pay for the project, or the value of the project to the government. However, stipulations shift risk to the agency, and the agency should understand the potential consequences before accepting them. Risk is minimized and optimally allocated through carefully crafted M&V requirements, including diligent estimation of any stipulated values.

3.2 RISK, RESPONSIBILITY, AND PERFORMANCE MATRIX

A project-specific Risk, Responsibility, and Performance Matrix (referred to below simply as the "Responsibility Matrix") is required for Super ESPC projects. This matrix details risks, responsibilities, and verification requirements that should be considered when developing performance contracts. The matrix is developed to help identify the important project risks, assess their potential impacts, and clarify the party responsible for managing the risk.

The first step in developing an M&V Plan for a Super ESPC project is the completion of a project-specific Responsibility Matrix. Early in the project development process, the ESCO and the agency review Federal Energy Management Program's (FEMP's) Responsibility Matrix and evaluate how to allocate the key responsibilities.

The Responsibility Matrix, shown in Table 3-1, describes typical financial and operational issues and their influence on ESPC contracts. The table lists the primary factors that impact the determination of savings and illustrates how their definition indicates which party—the ESCO or the government agency, or perhaps neither—is responsible for each factor. These risks fall into three primary categories: financial, operational, and performance. Each category has several subcategories.

For Super ESPC projects, the Responsibility Matrix is first included in the Preliminary Assessment and finalized in the Final Proposal. A blank column in the Responsibility Matrix is completed by the ESCO to describe the proposed allocation of responsibilities in the project, and an additional column can be added for the agency's assessment. The final version will only contain allocations agreed upon by both the ESCO and agency..

Completing the Responsibility Matrix serves as a useful exercise in understanding the approaches required in the M&V Plan because the Matrix indicates what factors are the responsibility of the ESCO and thus need to be documented during the life of the contract term. The allocation of responsibility must take into account the agency's resources and preferences and the ESCO's ability to control certain factors. In general, a contract objective may be to release the ESCO from responsibility for factors beyond its control, such as building occupancy and weather, yet hold the ESCO responsible for controllable factors (risks), such as maintenance of equipment efficiency.

Table 3-1 Energy Savings Performance Contract Risk, Responsibility, and Performance Matrix[4]

Responsibility/Description	Contractor Proposed Approach
1. Financial	
a. Interest rates: Neither the contractor nor the agency has significant control over prevailing interest rates. Higher interest rates will increase project cost, financing/project term, or both. The timing of the Task Order signing may impact the available interest rate and project cost.	
b. Construction costs: The contractor is responsible for determining construction costs and defining a budget. In a fixed-price design/build contract, the agency assumes little responsibility for cost overruns. However, if construction estimates are significantly greater than originally assumed, the contractor may find that the project or measure is no longer viable and drop it before TO award. In any design/build contract, the agency loses some design control. Clarify design standards and the design approval process (including changes) and how costs will be reviewed.	
c. M&V confidence: The agency assumes the responsibility of determining the confidence that it desires to have in the M&V program and energy savings determinations. The desired confidence will be reflected in the resources required for the M&V program, and the ESCO must consider the requirement prior to submittal of the final proposal. Clarify how project savings are being verified (e.g., equipment performance, operational factors, energy use) and the impact on M&V costs.	
d. Energy Related Cost Savings: The agency and the contractor may agree that the project will include savings from recurring and/or one-time costs. This may include one-time savings from avoided expenditures for projects that were appropriated but will no longer be necessary. Including one-time cost savings before the money has been appropriated may involve some risk to the agency. Recurring savings generally result from reduced O&M expenses or reduced water consumption. These O&M and water savings must be based on actual spending reductions. Clarify sources of non-energy cost savings and how they will be verified.	
e. Delays: Both the contractor and the agency can cause delays. Failure to implement a viable project in a timely manner costs the agency in the form of lost savings and can add cost to the project (e.g., construction interest, remobilization). Clarify schedule and how delays will be handled.	
f. Major changes in facility: The agency (or Congress) controls major changes in facility use, including closure. Clarify responsibilities in the event of a premature facility closure, loss of funding, or other major change.	
2. Operational	
a. Operating hours: The agency generally has control over operating hours. Increases and decreases in operating hours can show up as increases or decreases in "savings" depending on the M&V method (e.g., operating hours multiplied by improved efficiency of equipment vs. whole-building/utility bill analysis). Clarify whether operating hours are to be measured or stipulated and what the impact will be if they change. If the operating hours are stipulated, the baseline should be carefully documented and agreed to by both parties.	

[4] *ESPC Risk, Responsibility, and Performance Matrix* is included in the Super ESPC master contract.

Responsibility/Description	Contractor Proposed Approach
b. Load: Equipment loads can change over time. The agency generally has control over hours of operation, conditioned floor area, intensity of use (e.g., changes in occupancy or level of automation). Changes in load can show up as increases or decreases in "savings" depending on the M&V method. **Clarify whether equipment loads are to be measured or stipulated and what the impact will be if they change.** If the equipment loads are stipulated, the baseline should be carefully documented and agreed to by both parties.	
c. Weather: A number of energy efficiency measures are affected by weather, which neither the contractor nor the agency has control over. Should the agency agree to accept risk for weather fluctuations, it will be contingent upon aggregate payments not exceeding aggregate savings. **Clearly specify how weather corrections will be performed.**	
d. User participation: Many energy conservation measures require user participation to generate savings (e.g., control settings). The savings can be variable, and the contractor may be unwilling to invest in these measures. **Clarify what degree of user participation is needed and utilize monitoring and training to mitigate risk.** If performance is stipulated, document and review assumptions carefully and consider M&V to confirm the capacity to save (e.g., confirm that the controls are functioning properly).	
3. Performance	
a. Equipment performance: The contractor has control over the selection of equipment and is responsible for its proper installation, commissioning, and performance. The contractor has the responsibility to demonstrate that the new improvements meet expected performance levels, including specified equipment capacity, standards of service, and efficiency. **Clarify who is responsible for initial and long-term performance, how it will be verified, and what will be done if performance does not meet expectations.**	
b. Operations: Performance of the day-to-day operations activities is negotiable and can impact performance. However, the contractor bears the ultimate risk regardless of which party performs the activity. **Clarify which party will perform equipment operations, the implications of equipment control, how changes in operating procedures will be handled, and how proper operations will be assured.**	
c. Preventive Maintenance: Performance of day-to-day maintenance activities is negotiable and can impact performance. However, the contractor bears the ultimate risk regardless of which party performs the activity. **Clarify how long-term preventive maintenance will be assured, especially if the party responsible for long-term performance is not responsible for maintenance (e.g., contractor provides maintenance checklist and reporting frequency). Clarify who is responsible for performing long-term preventive maintenance to maintain operational performance throughout the contract term. Clarify what will be done if inadequate preventive maintenance impacts performance.**	
d. Equipment Repair and Replacement: Performance of day-to-day repair and replacement of contractor-installed equipment is negotiable; however it is often tied to project performance. The contractor bears the ultimate risk regardless of which party performs the activity. **Clarify who is responsible for performing replacement of failed components or equipment replacement throughout the term of the contract. Specifically address potential impacts on performance due to equipment failure. Specify expected equipment life and warranties for all installed equipment. Discuss replacement responsibility when equipment life is shorter than the term of the contract.**	

4.1 OVERVIEW OF M&V OPTIONS A, B, C, AND D

The measurement and verification (M&V) protocol mandated for projects conducted under the Super Energy Savings Performance Contract (Super ESPC) is the Federal Energy Management Program (FEMP) M&V Guidelines: Measurement and Verification for Federal Energy Projects. The FEMP Guidelines are an application of the International Performance Measurement and Verification Protocol[5] (IPMVP). Both of these guidelines group M&V methodologies into four general categories: Options A, B, C, and D. The options are generic M&V approaches for energy and water saving projects.

M&V approaches are divided into two general types: retrofit isolation and whole-facility. Retrofit isolation methods look only at the affected equipment or system independent of the rest of the facility; whole-facility methods consider the total energy use and de-emphasize specific equipment performance. One primary difference in these approaches is where the boundary of the energy conservation measure (ECM) is drawn, as shown in Figure 4-1. All energy used within the boundary must be considered. Options A and B are retrofit isolation methods; Option C is a whole-facility method; Option D can be used as either, but is usually applied as a whole-facility method.

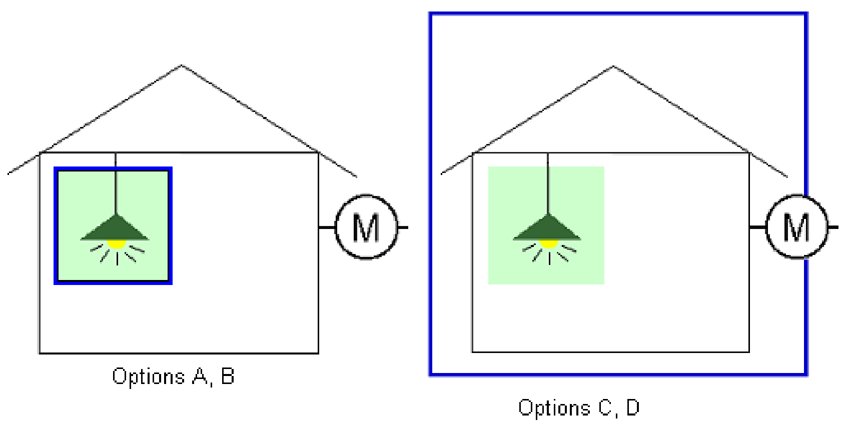

Figure 4-1 Retrofit Isolation (Options A and B) vs Whole-Facility M&V Methods (Options C and D)

The four generic M&V options are summarized in Table 4-1 and described in more detail below. Each option has advantages and disadvantages based on site-specific factors and the needs and expectations of the agency (see Chapter 5). While each option defines an approach to determining savings, it is important to realize that savings are not directly measured, and all savings are estimated values. The accuracy of these estimates, however, will improve with the number and quality of the measurements made. Although not required in Super ESPC projects, the accuracy of savings estimates can be quantified, as discussed in Section 5.4.

5 *International Performance Measurement and Verification Protocol: Concepts and Options for Determining Energy and Water Savings Volume I*, EVO-10000 -1.2007, Efficiency Valuation Organization.

Table 4-1 Overview of M&V Options A, B, C, and D

M&V Option	Performance[1] and Usage[2] Factors	Savings Calculation
Option A—Retrofit Isolation with Key Parameter Measurement	This option is based on a combination of measured and estimated factors when variations in factors are not expected. Measurements are spot or short-term and are taken at the component or system level, both in the baseline and post-installation cases. Measurements should include the key performance parameter(s) which define the energy use of the ECM. Estimated factors are supported by historical or manufacturer's data. Savings are determined by means of engineering calculations of baseline and post-installation energy use based on measured and estimated values.	Direct measurements and estimated values, engineering calculations and/or component or system models often developed through regression analysis Adjustments to models are not typically required.
Option B—Retrofit Isolation with All Parameter Measurement	This option is based on periodic or continuous measurements of energy use taken at the component or system level when variations in factors are expected. Energy or proxies of energy use are measured continuously. Periodic spot or short-term measurements may suffice when variations in factors are not expected. Savings are determined from analysis of baseline and reporting period energy use or proxies of energy use.	Direct measurements, engineering calculations, and/or component or system models often developed through regression analysis Adjustments to models may be required.
Option C – Utility Data Analysis	This option is based on long-term, continuous, whole-building utility meter, facility level, or sub-meter energy (or water) data. Savings are determined from analysis of baseline and reporting period energy data. Typically, regression analysis is conducted to correlate with and adjust energy use to independent variables such as weather, but simple comparisons may also be used.	Based on regression analysis of utility meter data to account for factors that drive energy use Adjustments to models are typically required.
Option D—Calibrated Computer Simulation	Computer simulation software is used to model energy performance of a whole-facility (or sub-facility). Models must be calibrated with actual hourly or monthly billing data from the facility. Implementation of simulation modeling requires engineering expertise. Inputs to the model include facility characteristics; performance specifications of new and existing equipment or systems; engineering estimates, spot-, short-term, or long-term measurements of system components; and long-term whole-building utility meter data. After the model has been calibrated, savings are determined by comparing a simulation of the baseline with either a simulation of the performance period or actual utility data.	Based on computer simulation model (such as eQUEST) calibrated with whole-building or end-use metered data or both. Adjustments to models are required.

1 Performance factors indicate equipment or system performance characteristics, such as kW/ton for a chiller or watts/fixture for lighting.

2 Operating factors indicate equipment or system operating characteristics such as annual cooling ton-hours for chillers or operating hours for lighting.

4.2 DEVELOPING REGRESSION MODELS

All M&V options utilize models to predict the baseline and performance period energy use of the project or ECM based on the behavior of the appropriate independent variables. An independent variable is a parameter that is expected to change regularly and has a measurable effect on the energy use of a system or building. The models used to predict energy use, with the exception of Option D which utilizes simulation software, are often mathematical equations derived through regression analysis that incorporate key independent variables. Regression models involve an evaluation of the energy behavior of a facility or system to determine how it relates to one or more independent variables (e.g., weather, occupancy, production rate). Regression models are a technique often used to adjust baseline or performance period energy use to account for changes in weather, occupancy, or other factors between the baseline and performance periods. Proper applications of these routine adjustments are discussed in Section 5.2.

IPMVP 2007 Appendix B-2 and ASHRAE Guideline 14-2002 Annex D both have additional details on developing models by means of regression analyses as well as techniques for validating these models.

4.2.1 Independent Variables

An independent variable is a parameter that is expected to change regularly and has a measurable effect on the energy use of a system or building. Typical independent variables that drive energy consumption that can be incorporated in regression models include outdoor temperature, other weather parameters (e.g., heating or cooling degree days), occupancy, operating hours, and other variable site conditions.

Data on independent variables may be from a third party or may be tracked using onsite data collection, depending on their nature. Weather data are typically more reliable when supplied by an independent source, but should be validated with site data to ensure applicability.

Once the data have been collected, the mathematical model that is used to predict the baseline (or performance period) energy use is developed. The model should make intuitive sense—the independent variables should be reasonable and the coefficients should have the expected sign (positive or negative) and be within an expected range or magnitude.

4.2.2 Choosing a Model

There are various forms of models used in standard statistical practice. Examples of multi-variant regression models are included in IPMVP 2007 and ASHRAE Guideline 14.

One example of a linear multi-variant regression model for a weather-dependent ECM is shown in Equation 4-1 below. In models using weather data, it can be beneficial to define a custom temperature base for calculating HDD and CDD data based on the actual behavior of the building.[6]

Equation 4-1: Multi-Variant Regression Model for a Weather-Dependent ECM

$$E = B_1 + (B_2 \times T_i - T_{i-1})) + (B_3 \times HDD_i) + (B_4 \times CDD_i) +$$
$$(B_5 \times X_1) + (B_6 \times X_2) + (B_7 \times X_3)$$

where:

E	=	energy use
i	=	index for units of time for period
B_{1-7}	=	coefficients
T	=	ambient temperature
HDD	=	heating degree days using a base temperature of 60°F

[6] 2005 ASHRAE Handbook - Fundamentals, page 32.17.

CDD = cooling degree days using a base temperature of 65°F
X_n = independent steady-state variables

It is important that the best model type be used, which in turn will depend on the number of independent variables that affect energy use and the complexity of the relationships. Finding the best model often requires testing several models and comparing their statistical results. The number of coefficients should be appropriate for the number of observations. Similarly, the form of the polynomial should be suitable to number of independent variables. Additionally, the independent variables must be truly independent of one another. The model should be tested for possible statistical problems (e.g., autocolinearity[7]) and corrected.

Validation steps should include checks to make sure that statistical results meet acceptable standards. The statistical requirements outlined in Table 4-2 are examples of validation standards for mathematical models using typical statistical indicators. An example application of these indices is included in the Standard M&V Plan for Chiller Replacements (Appendix H). The statistical validity of models can be demonstrated using other published sources such as ASHRAE Guideline 14-2002. Specific goals should be set for validating mathematical models used in each project based on suitable levels of effort (see Chapter 5) and should be specified in the M&V Plan. Many analysis tools provide some of these statistical results, while others will need to be calculated.

Table 4-2 Statistical Validations Guidelines

Parameter Evaluated	Abbreviation	Suggested Acceptable Values	Purpose
Coefficient of determination	R^2	> 0.75	Indicates model's overall ability to account for variability in the dependent variable. Lower R^2 values may indicate independent variables may be missing or additional data is needed.
Coefficient of variation of root-mean squared error	C_V(RSME)	< 15%	Calculates the standard deviation of the errors, indicating overall uncertainty in the model
Mean Bias Error	MBE	+/- 7%	Overall indicator of bias in regression estimate. Positive values indicate higher than actual values; negative values indicate that regression under-predicts values.
t-statistic	t-stat	> 2.0	Absolute value >2 indicates independent variable is significant

4.2.3 Weather Data

If the energy savings model incorporates weather data, several issues should be considered:

- The relationship between temperature and energy use may vary depending upon the time of year. For example, an ambient temperature of 55°F in January has a different implication for energy usage than the same temperature in August. Thus, seasons may need to be addressed in the model.
- The relationship between energy use and weather may be nonlinear. For example, a 10°F change in temperature may result in a very different energy use impact if that change is from 75°F to 85°F rather than 35°F to 45°F.

[7] Autocolinearity can result when one or more important independent variables were left out of the model.

- Matching degree-day and other data with billing start and end dates.

4.2.4 Documentation

All models should be thoroughly documented including specifying model limits. Ideally, the range of values of the independent variables used to create the model span the entire range of possible conditions. Models are generally good only for the range of independent variables used in creating the regression model.

The criteria used for identifying and eliminating any available data must be documented. Outliers are data beyond the expected range of values (or two to three standard deviations away from the average of the data). The elimination of outliers, however, should be justified by abnormal or specific mitigating factors. If a reason for the unexpected data cannot be found, the data should be included in the analysis. Outliers should be defined using common sense as well as common statistical practice.

4.2.5 Savings Determination

In general, the procedure for determining energy savings with a regression model is as follows:

- Develop and validate an appropriate baseline model relating the baseline energy use during normal operations to key independent variables.
- Install ECMs and continuously measure the independent variables used in the baseline model. along with any additional variables that may be needed for performance period model development.
- Using the baseline model, estimate what the energy use would have been without the ECMs by driving the baseline model with the performance period weather or other independent variables.
- Calculate savings by comparing the predicted baseline energy use with the actual energy use of the performance period.

An alternative approach that is sometimes warranted includes creating a separate regression model to describe performance period energy use. Both the baseline and performance period models are then adjusted to the same period's conditions prior to comparison. This approach allows for calculation of normalized savings[8] based on a predefined set of parameters, such as typical weather. All independent variables and criteria for validating performance period models should be included in the M&V Plan.

The best regression model is one that is simple and yet produces accurate and repeatable savings estimates. Determining the best model often requires testing several models to find one that is easy enough to use and meets statistical requirements for accuracy (see Section 4.2).

[8] See Section 7.2.

4.3 OPTION A—RETROFIT ISOLATION WITH KEY PARAMETER MEASUREMENT

M&V Option A involves a retrofit or system level M&V assessment. The approach is intended for retrofits where key performance factors (e.g., end-use capacity, demand, power) or operational factors (e.g., lighting operational hours, cooling ton-hours) can be spot- or short-term-measured during the baseline and post-installation periods. Any factor not measured is estimated based on assumptions, analysis of historical data, or manufacturer's data.

All end-use technologies can be verified using Option A. However, the accuracy of this option is generally inversely proportional to the complexity of the measure. Thus, the savings from a simple lighting retrofit will typically be more accurately estimated with Option A than the savings from a more complicated chiller retrofit. If greater accuracy is required, Options B, C, or D may be more appropriate. Properly applied, an Option A approach:

- Ensures that baseline conditions have been properly defined
- Confirms that the proper equipment/systems were installed and that they have the potential to generate predicted savings
- Verifies that the installed equipment/systems continue to have the capacity to yield the predicted savings during the term of the contract

Option A can be applied when identifying that the potential to generate savings is the most critical M&V issue, including situations where:

- The magnitude of savings is low for the entire project or a portion of the project to which Option A is applied.
- The risk of not achieving savings is low.
- The independent variables that drive energy use are not difficult or expensive to measure, and are not expected to change.
- Interactive effects can be reasonably estimated or ignored
- Long-term measurements are not warranted
- The agency is willing to accept some uncertainty

4.3.1 Approach to Option A

Option A is an approach designed for projects in which the potential to generate savings must be verified, but the actual savings can be determined from short-term measurements, estimates, and engineering calculations. Performance period energy use is not measured throughout the term of the contract. Performance period energy use and baseline energy use are predicted using an engineering or statistical analysis of information that does not involve long-term measurements.

With Option A, savings are determined by measuring the key parameters such as capacity, efficiency, or operation of a system before and after a retrofit, and by multiplying the difference by an estimated factor. Using estimates is the easiest and least expensive method of determining savings. It can also be the least accurate and is typically the method with the greatest uncertainty in savings. This level of savings determination may suffice for certain types of projects where a single factor represents a significant portion of the savings uncertainty.

Option A is appropriate for projects in which both parties agree to a payment stream that is not subject to fluctuation due to changes in the operation or performance of the equipment. However, payments could be subject to change based on periodic measurements or non-routine adjustments.

4.3.1.1 Measurements

Within Option A, various methods and levels of accuracy determining savings are available. The level of accuracy depends on what measurements are made to verify equipment ratings, capacity, operating hours, and/or efficiencies; the quality of assumptions made; and the accuracy of the equipment inventory including nameplate data and quantity of installed equipment. There may be sizable differences between published information and actual operating data. Where discrepancies exist or are believed to exist, field-operating data should be obtained.

A key consideration in implementing Option A is identifying the parameters that will be measured and those that will be estimated. The key performance parameter(s) that the ESCO is responsible for should be measured in both the baseline and performance period cases, and savings should be calculated from these values. For example, the watts/fixture is the key performance parameter for a lighting retrofit.

Other parameters that affect energy use (e.g., operating hours) that the agency or no one controls, can be estimated and then stipulated in the contract. Where these other parameters are not known with sufficient certainty, they should be measured in the baseline case and then stipulated. The penalty associated with low accuracy is not achieving the estimated savings and the associated utility bill cost reductions. Appropriate sources of estimated values are discussed below.

4.3.1.2 Estimates

The estimated parameters will affect the reported savings over the entire contract term. All estimates should be based on reliable, documentable sources and should be known with a high degree of confidence. While direct measurements from short-term logging or existing EMCS records are the preferred information source, such information may not be available or may be costly to obtain. Sources of information on which estimations should be based include the following (in decreasing order of preference):

- Models derived from measurements and monitoring
- Manufacturer’s data or standard tables (such as lighting tables used in utility demand-side management programs)
- Manufacturer’s curves, such as pump, fan, and chiller performance curves
- Industry-accepted performance curves, such as standards published by the American National Standards Institute (ANSI), American Refrigeration Institute (ARI), and the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE)
- Typical Meteorological Year (TMY) weather data
- Observations of building and occupant behavior
- Facility operations and maintenance logs

Estimated parameters should *not* come from the following:

- Undocumented assumptions or "rules-of-thumb"
- Proprietary "black-box" algorithms or other undocumented software
- Handshake agreements with no supporting documentation
- Guesses at operating parameters
- Equations that do not make mathematical sense or are derived from questionable data

4.3.1.3 Ongoing Verification

The potential to generate savings may be verified through spot/short-term metering and inspections conducted immediately before and immediately after installation. Annual (or some other regular interval) inspections must be conducted to verify that the proper equipment/systems are installed and the equipment/systems are performing to specification. If conditions have changed, additional performance period measurements or non-routine adjustments may be appropriate.

4.3.2 M&V Considerations

Option A is for projects in which the potential to generate savings must be verified and actual savings can be determined from short-term measurements, estimates, and engineering calculations. Some considerations when using Option A approaches include:

- Option A methods can vary in the level of accuracy in determining savings and verifying performance. The level of accuracy depends on the validity of estimates, the quality of the equipment inventory, and the measurements that are made.
- Verifying proper ongoing operation and potential to perform is an important aspect of Option A.
- Option A is appropriate for relatively simple ECMs whose baseline and post-installation conditions (e.g., equipment quantities and ratings such as lamp wattages or motor kW) represent a significant portion of the uncertainty associated with the project.
- Option A methods are not suitable for ECMs whose performance is uncertain or unpredictable.

4.4 OPTION B—RETROFIT ISOLATION WITH ALL PARAMETER MEASUREMENT

M&V Option B is a retrofit isolation or system-level approach. The approach is intended for retrofits with performance factors (e.g., end-use capacity, demand, power) and operational factors (lighting operational hours, cooling ton-hours) that can be measured at the component or system level and where long-term performance needs to be verified. It is similar to Option A, but uses periodic or continuous metering of all energy quantities, or all parameters needed to calculate energy, during the performance period. This approach provides the greatest accuracy in the calculation of savings, but increases the performance-period M&V cost.

The Option B approach ensures the same items as Option A, but also:

- Determines energy savings using periodic or continuous measurement of energy use or all parameters needed to calculate energy use during the term of the contract.

Option B is typically used when any or all of these conditions apply:

- For simple equipment replacement projects with energy savings that are less than 20% of total facility energy use as recorded by the relevant utility meter or sub-meter (Option C is not applicable)
- When energy savings values per individual measure are desired
- When interactive effects can be estimated using methods that do not involve long-term measurements
- When the independent variables that affect energy use are not complex and excessively difficult or expensive to monitor
- When operational data on the equipment is available through control systems
- When sub-meters already exist that record the energy use of subsystems under consideration (e.g., a separate sub-meter for heating ventilation and air-conditioning (HVAC) systems)

4.4.1 Approach to Option B

Option B verification procedures involve the same items as Option A, but require more end-use metering. Option B relies on the physical assessment of equipment change-outs to ensure that the installation is to specification. The potential to generate savings is verified through observations, inspections, and spot/short-term/continuous metering of energy or proven proxies of energy use, such as variable frequency drive speed for motor power. Baseline models are typically developed by correlating metered energy use with key independent variables. Depending on the ECM, spot or short-term metering may be sufficient to characterize the baseline condition, and the continuous metering of one or more variables may occur after retrofit installation. It is appropriate to use spot or short-term measurements in the performance period to determine energy savings when variations in performance are not expected, and may support some normalized savings approaches (Section 7.2) though adjustments to the baseline and/or the performance period model(s). When variations are expected, it is appropriate to measure factors continuously during the contract period. Continuous monitoring of information can be used to improve or optimize the operation of the equipment over time, thereby improving the performance of the retrofit.

4.4.2 M&V Considerations

Option B is for projects in which the potential to generate savings must be verified and actual energy use during the contract term needs to be measured for comparison with the baseline model for calculating savings. Option B involves procedures for verifying the same items as Option A plus the determination of energy savings during the contract term through short-term or continuous end-use metering. Some considerations when using Option B approaches include:

- All end-use technologies can be verified with Option B; however, the degree of difficulty and costs associated with verification increases as metering complexity increases.

- The task of measuring or determining energy savings using Option B can be more difficult and costly than that of Option A. However, results are typically more precise using Option B than the use of estimations as defined for Option A.
- Periodic spot or short-term measurements of factors are appropriate when variations in loads and operation are not expected. When variations are expected, it is appropriate to measure factors continuously.
- Performing continuous measurements or periodic measurements over the term of the contract will account for operating variations and will result in closer approximations of actual energy savings. Continuous measurements provide long-term persistence data on the energy use of the equipment or system.
- Data collected for energy savings calculations can be used to improve or optimize the operation of the equipment on a real-time basis, thereby improving the benefit of the retrofit. For constant-load retrofits, however, there may be no inherent benefit of continuous over short-term measurements.

4.5 OPTION C—WHOLE-BUILDING DATA ANALYSIS

M&V Option C involves whole-facility utility or sub-meter data analysis procedures to verify the performance of retrofit projects in which whole-facility baseline and performance period data are available. Option C usually involves collecting historical whole-facility baseline energy use and related data and continuously measuring whole-facility energy use after ECM installation. Baseline and periodic inspections of the equipment are also needed. Energy savings under Option C are estimated by developing statistically representative models of whole-facility or sub-metered energy consumption (i.e., therms and/or kWh). This method confirms total energy savings, but does not measure the savings from individual components.

In general, Option C should be used with complex equipment replacement and controls projects for which predicted savings are relatively large, i.e., greater than about 10% to 20% of the site's energy use, on a monthly basis. Option C regression methods are valuable for measuring interactions between energy systems or determining the impact of projects that cannot be measured directly, such as insulation or other building envelope measures. Regression analysis requires experienced, qualified analysts, and Option C methods should be employed only for projects that meet the following requirements:

- Savings are predicted to be greater than about 10% to 20% of the overall consumption measured by the utility or sub-meter.
- At least 12 and preferably 24 months or more of pre-installation data are used to calculate a baseline model.
- At least 9 and preferably 12 months of performance period data are used to calculate annual savings.
- Adequate data on independent variables are available to generate an accurate baseline model, and procedures are in place to track the variables required for performance period models.

- Significant operational or other changes are not planned for the facility during the performance period, and procedures are in place to document changes that do occur at the site.

4.5.1 Approach to Option C

With Option C, energy savings are determined using whole-building utility meter or facility-level metered data. Savings are determined through analysis of utility data (therms, fuel oil, kW, kWh, etc.) and the independent variables that affect energy consumption. Regression models are developed to predict energy use based on the appropriate independent variables for the project. Although simple mathematical techniques utilizing utility bill comparison are sometimes used, they are unreliable and not recommended on federal ESPC projects. Regression models can take into account the impacts of weather and other independent variables on energy use, whereas simple utility bill comparison techniques cannot. The analysis requires an evaluation of the behavior of the facility as it relates to one or more independent variables (e.g., weather, occupancy, production rate) using regression analysis.

Utility data analysis can take several approaches to calculate savings, as described in Section 4.2.5 and Section 7.2. The key elements of these approaches include developing an appropriate baseline model which relates the baseline energy use to key independent variables, and continuously measuring the performance period energy use and the key independent variables. Savings are often calculated by comparing the energy use predicted by the baseline model using measured conditions with the actual energy use of the performance period. Alternately, performance period models may be developed if the baseline and performance period models are to be adjusted to typical conditions prior to comparison. Performance period models may also be needed if there is not a full year's worth of data available for the performance period.

4.5.2 Data Collection

Collecting, validating, and properly applying data are important elements of using utility data analysis. Option C techniques utilize three types of data: utility billing data, independent variables, and information on unrelated changes at the site. These data elements are discussed below.

4.5.2.1 Utility Billing Data

Utility billing data provide the basis for savings calculations by allowing a comparison of adjusted baseline models with performance period energy use. Regardless of the type of utility data used, a key to properly applying the data is ensuring that all start and end dates of the utility data are aligned with those of the independent variables. Collecting data on independent variables more often than collecting billing data can help align time frames. Billing data can be:

- Monthly billing data. Billing data should be measured at least once a month. There are typically two types of monthly billing data: total usage for the month and usage aggregated by time-of-use periods. Although either type of data can be used with a regression model, time-of-use is preferable because it provides more insight into usage patterns. In many cases, the peak demand is also recorded.

- Interval demand billing data. This type of billing data records the average demand (or energy use) for a given interval (e.g., 15 minutes) associated with the billing period, and typically includes peak demand charges.
- Stored energy billing data. Inventory readings or delivery information can be used to determine historical consumption for resources such as fuel oil, although sub-metering is preferred.

4.5.2.2 Other Site Changes

One of the challenges in applying Option C is accounting for factors beyond the ECM that affect overall site energy use, such as changes in square footage or loads. Tracking site changes provides a means for accounting for changes in energy use not associated with ECM installation. Adequately tracking the information needed to make these non-routine baseline adjustments can be a challenging task for long-term contracts and sites that have significant operational changes.

4.5.3 M&V Considerations[9]

The following points should be considered when conducting Option C utility data analyses for M&V:

- All independent variables that affect energy consumption must be specified, whether or not they are accounted for in the model. Critical variables can include weather, building occupancy, set points, time of day, number of meals served, etc. The most common variable for many types of ECMs is outdoor air temperature.
- The form and content of any separate performance period model(s) (if used) should be specified, along with the statistical validation targets. Statistical validity of the final regression model(s) must be demonstrated.
- Independent variable data need to correspond to the time periods of the billing meter reading dates and intervals. A plan for data collection, including sources and frequencies, should be specified.
- It is best to develop models using data in whole-year sets (12, 24, 36, or 48 months) so that any seasonal variations are not overstated.
- It is necessary to specify how site changes unrelated to the installation of the ECMs will be tracked over the performance period and how these data will be used to perform savings adjustments.
- If baseline energy use needs to be adjusted to incorporate minimum energy or operating standards (such as minimum ventilation rates or lighting levels), any modification to the model needs to be detailed.

4.6 OPTION D—CALIBRATED SIMULATION

Option D involves whole facility or system analysis procedures to verify the performance of retrofit projects using calibrated computer simulation models. Computer simulation is a powerful tool that allows an experienced user to model the building and mechanical systems in order to

[9] See ASHRAE Guideline 14-2002 and IPMVP Volume 1 (EVO 10000-1.2007) for additional information on utility billing analysis.

predict building energy use both before and after the installation of ECMs. The accuracy of the models is ensured by using metered site data to describe baseline and/or performance period conditions. Carefully constructed models can provide savings estimates for the individual ECMs on a project. More elaborate models generally improve the accuracy of savings calculations, but increase costs. A calibrated simulation of a building, however, can be utilized to easily evaluate savings from other potential improvements.

Building simulation requires experienced, qualified analysts, and Option D methods should be used only for projects that meet any or all of the following requirements:

- For complex equipment replacement and controls projects with too many ECMs to cost-effectively use retrofit isolation methods A or B
- When interactive effects between ECMs are too complex for retrofit isolation approaches, but need to be quantified
- When the Option C utility data analysis approach is not viable due to the overall level of savings being less than 20% of metered use
- When complex baseline adjustments are expected during the performance period
- When energy savings values per individual measure are desired
- When new construction projects are involved
- When savings levels are sufficient to warrant the cost of simulation
- When either baseline or performance period energy data, but not both, are unavailable or unreliable.

Option D is especially useful where a baseline does not exist (e.g., new construction or major building modification) or the factors responsible for savings are not easily measured (e.g., reduced solar gain and heat loss through new windows).

Situations for which computer simulation is not appropriate include:

- Analysis of ECM savings that can be more cost-effectively determined with other methods
- Buildings that cannot be adequately modeled, such as those with complex geometries or other unusual features
- Building systems or ECMs that cannot be adequately modeled, such as radiant barriers or demand-response control algorithms that are important in comparing baseline and performance period scenarios
- Projects with limited resources that are not sufficient to support the effort required for data collection, simulation, calibration, and documentation

Even for the simplest projects simulation modeling and calibration are time-intensive activities and should be performed by an accomplished building simulation specialist. Calibrated simulation analysis is an expensive M&V procedure, and should be undertaken only on projects that generate enough savings to justify its use.

4.6.1 Approach to Option D

M&V Option D for an existing building typically follows five general steps: 1) collect data; 2) input data and test baseline model; 3) calibrate the baseline model; 4) create and refine the performance period model; and 5) verify performance and calculate savings. Each of these steps is discussed in detail below.

The methodology followed for new construction projects is somewhat different, and is detailed in IPMVP Volume III.[10] One primary difference between the methods used for existing and new buildings is the availability of utility data. In new construction, the performance period model would be calibrated to utility data, whereas the baseline model would not due to lack of data, although comparisons with similar buildings can be made. This approach would also apply to an existing building that does not have reliable baseline energy data.

4.6.1.1 Collecting the Data

The data required for simulating an existing building can be voluminous, and ensuring collection of all data required to develop the simulation models is key. Collecting comprehensive baseline data is advised. All data collected do not necessarily need to be incorporated into the model, but may be included to meet specific model accuracy requirements. All collected information and inputs need to be documented in a format that allows due-diligence review. Inadequate, disorganized, self-contradictory, or conflicting documentation can be grounds for rejecting a submittal.

To obtain end-use data for model calibration, building subsystem metering must be included in the project M&V activities for baseline and performance periods. The specific sub-systems selected for monitoring are in most cases the installed ECMs and related systems. For ECMs such as windows or insulation that cannot be monitored, the impacted HVAC system should be sub-metered. The model calibration will benefit the most from monitoring the energy end uses for which the least information is available.

Required data typically includes:

- Utility bill records: Collect a minimum of 12 (and preferably 24, 36, or 48) consecutive months of utility bills for the months immediately before installation of the ECMs. The billing data should include meter read date, kWh consumption, peak electric demand, and heating fuel use (e.g., natural gas). Additional data in hourly and 15-minute formats may be required.
- Architectural, mechanical, and electrical drawings: as-built drawings are preferred.
- Site survey data: Comprehensive equipment and system data, typically collected during an investment grade audit, including:
  - HVAC systems: primary equipment (e.g., chillers and boilers): capacities, number, model and serial numbers, age, condition, operating schedules, etc.

[10] International Performance Measurements and Verification Protocol: Concepts and Options for Determining Energy Savings in New Construction, Volume III, April 2003.

- HVAC systems: secondary equipment (e.g., air-handling units, terminal boxes): characteristics, fan sizes and types, motor sizes and efficiencies, design-flow rates and static pressures, duct-system types, economizer operation, and type of controls
- HVAC system controls, including location of zones, temperature set-points, control set-points and schedules, and any special control sequences
- Lighting systems: number and types of lamps, with nameplate data for lamps and ballasts, lighting schedules, etc.
- Building occupants: population counts, occupation schedules in different zones
- Other major energy-consuming loads: type (industrial process, air compressors, water heaters, elevators), energy consumption, schedules of operation

- Site survey data that may be required in addition to data normally collected during an audit include:
  - Plug loads: summarize major and typical plug loads for assigning values per zone
  - Building envelope and thermal mass: dimensions and type of interior and exterior walls, properties of windows, and building orientation and shading from nearby objects. Infiltration rates are important, but are often difficult to determine
  - HVAC systems: ventilation air-flow rates can have a dramatic effect on energy use
- Short-term monitoring: The building energy management control system (EMCS) or data-logging equipment is set up to record system data as it varies over time. Typically, primary energy using systems and equipment involved in an ECM are monitored. These data may be required if particular subsystems (e.g., the chiller plant) need to be accurately modeled in order to determine savings. The data reveal how variable loads change with building operating conditions such as weather, occupancy, daily schedules, etc.
- Spot measurements of specific equipment: The power draw on lighting, plug load, HVAC equipment, and other circuits should be recorded to determine actual equipment operating powers.
- Operator interviews: Building operators can provide much of the above listed information and also any deviation in the intended operation of building equipment.
- Weather data: For calibration purposes, representative site weather data are required for the period in question, as outlined below (Section 4.6.3).
- Minimum code performance standards: For new construction projects and major renovations, minimum performance standards are often mandated for the baseline based on required codes.[11] If standards must be referenced in the baseline model, the minimum equipment efficiencies to represent the standards should be used.

[11] Minimum efficiency standards include CA Title 24, ASHRAE 90.1, IECC 2006, and state energy codes.

4.6.1.2 Inputting the Data and Running the Baseline Model

The data must be adapted as required to the baseline model and entered into the simulation program input files. Key data for inclusion are physical properties of the facility, equipment and system types and efficiencies, appropriate weather data, and control sequences. Specific attention should be given to systems that will be modified by ECMs.

The more site-specific data incorporated the more accurate the savings calculations, but the greater the costs. The simulation program's user guide and other resources should be consulted as needed to determine how to properly input the collected data into the model. From the volume of data collected, many decisions must be made to best represent the data in the simulation program's input file. This can be done most cost-effectively by an experienced building modeling specialist.

After the data have been inputted, a few simulations should be run to debug the model and the model output files should be checked to verify that there are no errors in running the program, such as:

- Does the HVAC system satisfy the heating and cooling loads?
- Are the equipment schedules correct?
- Are equipment efficiencies accurate?
- Are the model predictions reasonable?

4.6.1.3 Calibrating the Baseline Model

The baseline simulation model should be calibrated using the procedures described in Section 4.5.3 by comparing the energy usage and demand projected by the model with the usage and demand of the measured utility data. For new construction projects, the baseline energy use should be compared to other buildings that have similar operation and function. If required tolerances to the measured data are not met, the input data to the model should be refined until requirements are met.

The calibrated model should be documented by showing final input parameters for the model. This information, as well as the actual calibration results, needs to be provided in the M&V submittals.

4.6.1.4 Create and Refine the Performance Period Model

Starting with the calibrated baseline model, the model should be updated to include the building's ECMs to create the performance period model.

If individual savings levels from each ECM are desired, an approach that includes the interactive effects of the ECMs is to input the ECMs consecutively into the baseline model. Some software allows the modeler to create a rolling baseline by including the previous ECMs in the model. After each ECM has been modeled, the simulation is run. The first run is the baseline model, the second run is ECM 1, the third run is ECM 1 and ECM 2, the fourth run is ECM 1, ECM 2, and ECM 3, etc. After the final ECM has been inputted, the model should represent the performance period condition with all ECMs installed. This approach includes interactive effects in the savings for each ECM.

Determining the sequence to input the ECMs into the model is an important consideration in managing interactive effects. Typically, measures that will affect the overall heating and cooling loads of the building (e.g., envelope improvements or lighting upgrades) should be inputted first. Secondary ECMs are those that affect the HVAC subsystems, and the final ECMs that should be inputted are those affecting the central plant.

Some simulation programs run each ECM against the original baseline, which neglects any interactive effects between the measures. These intermediate results are not always 100% additive, as two ECMs that save 2% alone, may not save 4% combined. Considering the interactive effects of ECMs, these ECMs combined may save 3%. When using this approach, a final run including all measures must be executed to determine the interactive effects of all the ECMs. This approach does not allocate interactive effects to the individual ECMs.

4.6.1.5 Verifying Performance and Calculating Savings

The method used to determine savings will depend upon the phase of the project. During project development, proposed savings are determined by subtracting the results of the performance period model from the results of the calibrated baseline model, both using the agreed-upon weather data and facility operating conditions.

As with all M&V methods, after implementation of the ECMs the proper installation and operation of the ECMs must be verified periodically. Performance data should be collected not only to calibrate the model, but to validate that the new equipment and systems are installed and operating properly.

After the first year of performance, there are two options to calculate verified savings: 1) calibrate the performance period model and subtract the results of baseline model using the same conditions; or 2) subtract measured utility data for the performance period from the results of baseline model that was updated to actual conditions.

The first option requires that the performance period model be calibrated using the procedures described in Section 4.6.3. Update the performance period model using data collected during the performance period from site surveys, spot measurements, short-term monitoring, and utility data. Effort can be minimized by focusing data collection on the installed ECMs.

If savings are to be estimated for a specific year, actual weather and other data from that year must be used. If savings are to be normalized to typical conditions (see Section 7.2), for example, then typical weather data (e.g., TMY data) should be used. In any case, both the baseline model and the performance period model must be run with the same weather data. The weather data to be used are specified in the site-specific M&V Plan. Although time-intensive, Option D approaches are well suited to adjust models when significant site changes occur during the performance period.

If savings for each ECM are to be determined including interactive effects, the ECMs must be inputted consecutively into the model and simulations run after each input, as described above.

Individual ECM savings are determined by the difference in energy or demand use between two consecutive runs. The savings determined for the individual ECMs should total the savings determined from the baseline and performance period runs. It is important that savings be determined with both models using the same conditions (weather, occupancy schedules, set points, etc.), except for the characteristics of the installed ECMs.

The energy values and rate structure specified in the M&V Plan are applied to the energy savings determined by the model. If utility rates are included in the model, sufficient information on the savings should be provided so that cost calculations can be verified. When time-of-use charges or other variable usage schedules are applied, the demand (kW) and energy (kWh) savings must be broken down into the proper categories to determine cost savings (see Section 7.2).

4.6.2 Simulation Software

The most frequently used type of building energy simulation program for energy analyses are whole-building programs that create customized models of buildings and their systems, and employ hourly weather data to predict energy use. Such programs are very versatile, allowing the accurate modeling of most buildings through custom input data. Two of the most common public domain programs of this type are eQUEST and EnergyPlus.[12] A complete list of available energy simulation programs is maintained by the DOE.[13]

These building simulation programs require extensive input data to accurately model the energy use of a building. Recently, user interfaces have been improved that simplify the input process with graphical formats, and libraries of typical building components have been added to facilitate model development.

Simulation programs acceptable for Option D should have the following characteristics[14]:

- The program is commercially available, supported, and documented.
- The program has the ability to adequately model the project site and ECMs.
- The model can be calibrated to an acceptable level of accuracy.
- The program allows the use of actual weather data in hourly format.

4.6.3 Model Calibration[15]

The model calibration for existing buildings is accomplished by linking simulation inputs to actual operating conditions and comparing simulation results with whole-building and/or end-use data. The simulation may be of a whole facility or just for the end use or system affected by the ECM. Both baseline and performance period models should be calibrated wherever possible. Model calibration is typically an iterative process of adjusting model inputs and re-comparing

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12 eQUEST is available through http://doe2.com/equest/ (current release is eQUEST 3.6 and 3.61b) and EnergyPlus is available through http://www.eere.energy.gov/buildings/energyplus/.

13 See http://www.eere.energy.gov/buildings/tools_directory/subjects_sub.cfm

14 For more information on building simulation program elements See ASHRAE 90.1-2004 Energy Standard for Buildings Except Low-Rise Residential Buildings, Section G.2 or ASHRAE Guideline 14-2002.

15 See ASHRAE Guideline 14-2002 and IPMVP Volume 1 (EVO 10000-1.2007) for additional information on simulation modeling and validation techniques.

the results to measured data. A model is considered in calibration when the statistical indices demonstrating calibration have been met. Expected calibration requirements should be specified in the project-specific M&V Plan, and industry standard guidelines are included in Table 4-3. These requirements should be adjusted as required to meet the needs of the project.

For most models, there are multiple levels of calibration that can be performed:

- System level calibration with hourly monitored data
- Whole-building level calibration with monthly utility data
- Whole-building level calibration with hourly utility data

Determining the level of calibration that is needed depends on the value of the project, the availability of data, and the need for certainty in the savings estimates. All models should be calibrated to monthly data at a minimum. Simulation models that focus on specific systems should be calibrated to system level data. Also, calibrating the models to hourly data will help ensure accuracy, especially for determining peak demand savings. Calibrating a computer simulation to measured utility data necessitates that actual weather data be used, as discussed below.

The calibration procedures should apply to all energy sources (demand, electricity, natural gas, etc.), but should focus on the primary source(s) of savings. Each of these model calibration strategies is discussed below.

4.6.3.1 Weather Data

The first step in calibrating a model is updating and running the model using weather data that correspond precisely to the same calendar days as each utility bill. Programs that allow the use of only average weather files or weather data from only a few representative periods per month or per season are not suitable for the calibration techniques required for Option D.

Obtaining weather data for the appropriate location and time-period is an important step in calibrating any simulation model. Several resources are available for getting real-time weather data and converting them into the proper format for use with the simulation software. DOE maintains a website[16] that provides weather data from 1998 to the present from up to 4,000 weather stations. Some data may be missing, but can be extrapolated from the DOE's database.[17] The database provides data in a format used by Energy Plus, but can be converted for use with eQUEST and other programs.[18] Since using actual weather data can be time consuming, it is sometimes appropriate to modify average weather to more closely match the actual weather.[19]

The time period and frequency of the weather data need to align with the utility data periods, which can require data manipulation. The measure-specific M&V Plan must specify which

[16] The DOE website is http://www.eere.energy.gov/buildings/energyplus/cfm/weatherdata/weather_request.cfm .

[17] Detailed information on the data can be found in *Real-Time Weather Data Access Guide, User's Guide NREL/BR-550-34303 March 2006*, National Renewable Energy Laboratory. The FAQ and instructions on this web page should be followed to fill in the missing data: http://www.eere.energy.gov/buildings/energyplus/cfm/weatherdata/faq.cfm

[18] Weather file converter software is available through http://doe2.com/index_Wth.html .

[19] See http://gundog.lbl.gov/ for discussion on simulation issues.

weather data sources will be used, including both the source of the data and the physical location of the weather station.

After the model has been calibrated using actual weather data, the building's energy use may be adjusted to average-year weather. Average weather data may be obtained from ASHRAE (WYEC2) and the National Renewable Energy Laboratory (TMY2).[20]

4.6.3.2 Statistical Indices

For all of these approaches, two prescribed statistical indices (described below) must be calculated in order to declare a model calibrated: the mean bias error (MBE) and the coefficient of variation of the root mean squared error C_v(RMSE).[21] The recommended calibration requirements are those specified by ASHRAE Guideline 14. Specific calibration goals should be set for each project based on appropriate level of effort (see Chapter 5). This process should be applied to electricity (kWh), demand (kW), and all other fuels used.

In addition to statistical indices, graphical comparison techniques can be an effective tool understanding the variances present in a model. Simple or advanced methods of graphical comparison techniques can be effective, and are detailed in ASHRAE Guideline 14.

As mentioned above, actual weather corresponding to the time period in question should be used in the model. Typically, the energy consumption predicted by the model and measured by the utility or sub-meter are determined for every month or interval in the data set, as well as for the whole year or period, and statistical analyses are performed on the results. The same techniques can be applied to hourly and subsystem data. The statistical values that need to be calculated are MBE and C_v (RMSE).

- MBE—mean bias error. The MBE indicates how well the energy consumption is predicted by the model as compared to the measured data. Positive values indicate that the model overpredicts actual values; negative values indicate that the model underpredicts actual values. However, it is subject to cancellation errors, where the combination of positive and negative values serves to reduce MBE. To account for cancellation errors, the C_V(RSME) is also needed.
- C_V(RSME)— coefficient of variation of the root-mean-squared error. This value indicates the overall uncertainty in the prediction of whole-building energy usage. The lower the C_V(RSME), the better the calibration. This value is always positive.

The mean bias error is calculated by subtracting the simulated energy consumption from the measured energy consumption for all the intervals over a given time period. The differences from each interval are summed and then divided by the sum of the measured energy consumption over the same time period. MBE is calculation is expressed in Equation 4-2.

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[20] A comprehensive list of sources for weather data is available at http://www.eere.energy.gov/buildings/energyplus/weatherdata_sources.html.

[21] See ASHRAE Guideline 14-2002 and Section 4.2.2 for additional information.

Equation 4-2: Measured Energy Consumption

$$MBE(\%) = \frac{\sum_{Period} (S - M)_{Interval}}{\sum_{Period} M_{Interval}} \times 100$$

Where:

M is the measured kWh or fuel consumption during the time interval
S is the simulated kWh or fuel consumption during the same time interval

The C_v(RSME) is a normalized measure of variability between two sets of data. For calibrated simulation purposes, it is obtained by squaring the difference between paired data points, summing the squared differences over each interval through the period, and then dividing by the number of points, which yields the mean squared error. The square root of this quantity yields the root mean squared error (RMSE). The C_v(RMSE), is obtained by dividing the RMSE by the mean of the measured data for the period.

The root mean square error for the period is calculated using Equation 4-3.

Equation 4-3: Root Mean Square Error

$$RMSE_{Period} = \sqrt{\frac{\sum (S - M)_{Interval}^{\;\;2}}{N_{Interval}}}$$

Where:

$N_{Interval}$ are the number of time intervals in the monitoring period.

The mean of the measured data for the period is calculated using Equation 4-4.

Equation 4-4: Mean of the Measured Data

$$A_{Period} = \frac{\sum_{Period} M_{Interval}}{N_{Interval}}$$

The Cv(RSME) is calculated using Equation 4-5.

Equation 4-5: Cv(RSME)

$$Cv(RMSE_{Period}) = \frac{RMSE_{Period}}{A_{Period}} \times 100$$

The primary differences in applying these indices to the various data sets (monthly, hourly, sub-metered) are 1) the acceptable values of the indices and 2) the definition of “interval” and “period” in each of the equations above. The application of these statistical indices for each level of calibration is detailed in the sections below.

The recommended acceptable values for each approach are included in Table 4-3. These values have been adopted from ASHRAE Guideline 14. Specific calibration goals should be set for each project based on the appropriate level of effort (see Chapter 5) and should be specified in the project-specific M&V Plan. For existing buildings, the model calibration will occur prior to contract award, and both the calibration goals and results should be included in the IGA.

Table 4-3 Acceptable Calibration Tolerances[22]

Calibration Type	Index	Acceptable Value*
Monthly	MBE_{month}	± 5%
	$Cv(RMSE_{month})$	15%
Hourly	MBE_{Month}	±10 %
	$Cv(RMSE_{Month})$	30%

*Lower values indicate better calibration

4.6.3.3 Subsystem Level Calibration with Monitored Data

Calibration of a building model's subsystems to measured data may be required to enhance or ensure the overall accuracy of the model meets specified targets. The model's hourly predicted energy usage (kWh, therms, or Btu) is compared against measured hourly energy usage for the monitored building subsystems to determine whether the model accurately predicts subsystem level usage.

Most simulation programs, including eQUEST, output subsystem usage values minimally in 1-hour intervals. Therefore, for calibration, measured data must be averaged over each hour. For example, if 15-minute chiller demand (kW) data are collected, they must be averaged into hourly values.

When applying the statistical equations above to sub-metered data, the interval is an hour and the period can be defined by the user.

4.6.3.4 Whole-Building Level Calibration with Monthly Data

Comparing energy use projected by the building model with monthly utility bills is the minimum level of calibration that should be conducted on any model of an existing building with monthly utility data available. In the statistical equations above, the interval is a month and the period is a year.

When using monthly data, an additional check of the monthly variances should be made by calculating MBE by defining both the interval and the period as a month.

Example calibration calculations and results using monthly data are shown in Table 4-4. The results show that in addition to meeting the overall MBE and CV (RMSE) goals, the MBE for each month was also below the target value.

22 ASHRAE Guideline 14-2002, Section 6.3.3.4.2.2.

4.6.3.5 *Whole-Building Level Calibration with Hourly Data*

When hourly data are applied, the interval is an hour and the period can be defined by the user, and often a 1-month billing period is used. These indices, however, may be calculated for the entire period or for weekdays, weekends, and holidays separately.[23]

Table 4-4 Example Calculations to Determine Monthly Model Calibration

Month	2,006 Measured kWh (M)	eQUEST Simulated kWh (S)	S-M	MBE	Squared Error
Jan	839,040	842,236	3,196	0%	10,212,435
Feb	814,080	774,882	(39,198)	5%	1,536,448,710
Mar	766,080	827,555	61,475	-8%	3,779,175,625
Apr	874,555	928,017	53,462	-6%	2,858,226,075
May	984,960	1,077,269	92,309	-9%	8,520,951,481
Jun	960,000	1,005,105	45,105	-5%	2,034,461,025
Jul	1,079,040	1,184,382	105,342	-10%	11,096,884,293
Aug	956,160	1,034,555	78,395	-8%	6,145,776,025
Sep	908,160	1,009,812	101,652	-11%	10,333,192,128
Oct	888,960	999,842	110,882	-12%	12,294,831,230
Nov	952,320	840,194	(112,126)	12%	12,572,295,939
Dec	871,680	822,511	(49,169)	6%	2,417,626,946
Total	10,895,035	11,346,360	451,325	-4%	73,600,081,912
	<u>Overall Results:</u>				
	MBE_{month}	-4%			
	Cv(RMSE):	9%			

4.6.4 M&V Considerations

Many issues must be considered and addressed in developing a project-specific M&V Plan using Option D. Some of the more common steps are outlined below.

- Use an experienced building modeling professional. Although new simulation software packages make much of the process easier, a program's capabilities and real data requirements cannot be fully understood by inexperienced users, and resulting models may not be accurate.
- Determine the availability of utility bill data.
- Determine whether hourly or monthly billing data are available and whether meters can be installed to collect hourly data. Calibrations to hourly data are generally more accurate than calibrations to monthly data because there are more points to compare. Hourly energy or demand data, however, are generally only available for a utility's largest customers or may be collected with portable data loggers. If only monthly billing data are available, conducting additional short-term monitoring of building sub-systems can improve the accuracy of the model.

23 Bou-Saada, T.E. and J.S. Haberl, "An Improved Procedure for Developing Calibrated Hourly Simulation Models," International Building Performance Simulation Association, Report No. ESL-PA-95/08-01, 1995.

- Use actual equipment performance data in the simulation models. Many software packages have libraries of HVAC equipment that closely match actual system performance. Be cautious and investigate the library HVAC description to be sure it is a good representation of the real system and consider developing user-defined equipment performance curves based on field measurements or manufacturer's data.
- Specify spot measurements and short-term monitoring of key parameters for both the baseline and performance period models. Spot and short-term measurements augment the whole-building data and more accurately characterize building systems. It is recommended that an end use be monitored over a period that captures the full range of the equipment's operation (e.g., spring and summer for cooling systems. The data must also be collected in a way that facilitates sub-system level calibration. Careful selection of spot measurements and short-term monitoring is necessary because it can add significant cost and time to the project.
- Use trend data to determine actual controls. Sequencing of building controls is difficult to interpret from interviews, site surveys, manufacturer's data, and spot measurements. The best way to ascertain actual sequences is through trending data. Sometimes, the EMCS systems can be utilized to determine actual operating scenarios. However, the capability for data storage in many systems may be limited.
- Specify model calibration procedures that will be followed for monthly, hourly, or subsystem data for both the baseline and performance period models. Prescribe statistical calibration requirements based on the accuracy required for the project.
- Specify the simulation program and version and the source of weather data used (on-site, local weather station or typical weather data).
- Clearly explain how savings will be calculated after the first year. Keeping models up to date can be expensive. For projects without substantial site changes expected, an Option C utility billing analysis approach may be viable.[24] Regardless of how savings are calculated each year, the ongoing performance of the measures needs to be verified periodically.

[24] IPMVP Volume 1 2007, Section 4.10.4

Since the primary purpose of measurement and verification (M&V) is to validate payments or performance guarantees, the cost of M&V should be less than the payment amount or guarantee that is at risk. Consequently, the objective of M&V should not necessarily be to derive a precise energy savings number, but rather to ensure that energy services companies (ESCOs) properly complete their projects and that the resulting energy savings are reasonably close to the savings claimed. The appropriate level of M&V rigor and accuracy is a level that protects the project investment and fulfills the intent of the federal legislative requirements. Careful consideration of the M&V level, type, and rigor benefits both parties and can help mitigate potential problems during the performance period.

In general, the selection of a project specific M&V method is based upon:

- Project costs and expected savings
- Complexity of the ECM
- Number of interrelated ECMs at a single facility
- Uncertainty or risk of savings being achieved
- Risk allocation between the parties
- Other uses for M&V data and systems

This chapter discusses these issues, presents some rules of thumb to use when selecting an M&V approach, and discusses a methodology for evaluating project-specific M&V options. Additional discussion is provided on balancing M&V costs and technical rigor, as well as tips on minimizing uncertainty in the savings results.

5.1 KEY ISSUES IN SELECTING THE APPROPRIATE M&V APPROACH

The level of certainty and thus effort required to verify both a project's potential to perform and its actual performance will vary from project to project. The contract and/or the project-specific M&V plan should be prepared with serious consideration of what M&V requirements, reviews, and costs will be specified. Some key factors, outlined below, should be considered when choosing the M&V options and techniques to use for each Energy Savings Performance Contract (ESPC) project.

5.1.1 Value of ECM in Terms of Projected Savings and Project Costs

The scale of a project, energy rates, term of the contract, comprehensiveness of energy conservation measures (ECMs), the benefit-sharing arrangement, and the magnitude of savings can all affect the value of the ECM or ESPC project. The M&V effort should be scaled to the value of the project so that the value of the information provided by the M&V activity is appropriate to the value of the ECM and the project itself.

For Super ESPC projects, the average annual M&V costs are 3.3%[25] of annual project cost savings. Some more complex ECMs will often warrant greater M&V costs, but the overall M&V costs for the project are typically balanced by other ECMs that do not require substantial annual activities.

5.1.2 Complexity of ECM or System

More complex projects may require more complex (and thus more expensive) M&V methods to determine energy savings. In general, the complexity of isolating the savings is the critical factor. For example, a complicated chiller measure may not be difficult to assess if there are energy sub-meters and monitoring systems dedicated to the chiller system.

When defining the appropriate M&V requirements for a given project, it is helpful to consider ECMs as being in one of the following categories (listed in order of increasing M&V complexity):

- Constant load, constant operating hours
- Constant load, variable operating hours
- Variable hours with a fixed pattern
- Variable hours without a fixed pattern (e.g., weather-dependent)
- Variable load, variable operating hours
- Variable hours or load with a fixed pattern
- Variable hours or load without a fixed pattern (e.g., weather-dependent)

5.1.3 Number of Interrelated ECMs at a Single Facility

If multiple ECMs are being installed at a single site, the savings from each measure may be, to some degree, related to the savings resulting from other measures or other non-ECM activities at the facility. Examples include interactive effects between lighting and HVAC measures or between envelope improvements and a chiller replacement. In these situations, it may not be possible to isolate and measure one system in order to determine savings. Thus, for multiple, interrelated measures, whole-building Options C or D may be the most appropriate.

5.1.4 Risk of Achieving Savings

The importance of the M&V activities is often tied to the confidence associated with the estimated energy or cost savings. An ECM with which the facility staff is familiar may, subjectively, require less M&V rigor than ECMs that are less well known. Similarly, unproven technologies may warrant additional attention.

A simple method of estimating payment risk can be based on the estimated project value, technical uncertainty, and project sponsor experience. Such a method assumes that, as a starting point, all projects will be inspected to verify the project's potential to perform and estimate savings uncertainty and payment risk. A simple illustration of this method is shown in Table 5-1.

[25] Costs are based on cost schedules from 166 Super ESPC projects.

Table 5-1 Example Estimate of Savings Risk

Sample Project	Estimated Savings	Estimated Uncertainty	Savings Risk
Small lighting	$50,000	10%	$5,000
Large custom	$500,000	20%	$100,000

A limit on the M&V budget can then be established as a percentage of the project's payment risk before an M&V plan is specified. As illustrated, smaller projects consisting of predictable technologies have less payment risk (and thus a lower M&V budget cap) than large projects that include less predictable technologies.

In the same example, for the "large custom" measure, two M&V approaches may be evaluated based on their benefit-to-cost ratio, as indicated Table 5-2. In this example M&V Option C appears to be the better approach.

Table 5-2 Example Benefit-to-Cost Evaluation for M&V

Sample Project	Estimated Savings	Estimated Uncertainty (No M&V)	Savings Risk (No M&V)	Proposed M&V Method	Estimated Annual M&V Cost	Resulting Savings Uncertainty/ Savings Risk	Benefit-to-Cost Ratio: Risk Reduction in Savings/M&V Cost
Large custom	$500,000	20%	$100,000	Option C	$25,000	10% / $50K	2.0
Large custom	$500,000	20%	$100,000	Option B	$50,000	8% / $40 K	1.2

Accuracy requirements for measuring and verifying savings are either defined by the federal agency in its RFP or negotiated with the ESCO. In either case, the required level of measurement and verification effort is specified in the task order between the federal agency and the ESCO in the form of the M&V plan. This plan must be developed in early phases of a project's development to ensure that (a) M&V is not left as an afterthought or that (b) inadequate funding has been allocated to the required M&V activities.

5.1.5 Responsibility Allocation Between the ESCO and the Federal Agency

For Super ESPC projects, the achievement of guaranteed cost and energy savings must be verified each year. At a minimum, the ESCO and the federal agency must verify that the installed equipment/systems have been properly maintained, continue to operate correctly, and continue to have the potential to generate the predicted savings. Although annual reports may be required for establishing savings guarantees, interim reports can be prepared semi-annually for more complex projects. This ensures that the M&V monitoring and reporting systems are working properly; it also allows fine-tuning of measures throughout the year based on operational feedback, and it helps avoid surprises at the end of the year.

Typically, the aspects of the projects that are measured and verified are those for which the ESCO is held responsible. The Responsibility Matrix and contract should specify how savings will be determined and thus what needs to be verified. For example, variations in the operating hours of a facility during the term of a task order may be an acceptable risk to the federal agency. For example, operating hours may be determined by short-term measurements rather than continuously measured for purposes of payment.

5.1.5.1 Other Uses for M&V Data and Systems

Often, the array of instrumentation installed and the measurements collected for M&V can be used for other purposes, including commissioning and system optimization. Data and systems are more cost-effective if they are used to meet several objectives, and not just those of the M&V plan. In addition, savings could be quantified beyond the requirements of the performance contract. This information could be useful for allocating costs among different tenants, planning future projects, or allocating research.

5.2 DETERMINING AN M&V APPROACH

An M&V approach must be tailored for the specific project, based on the project's costs, savings, objectives, and constraints. This section outlines some general criteria that can be used to determine an approach, and presents the M&V Planning Tool that provides general procedures to develop a project-specific M&V approach.

5.2.1 General Criteria for Selecting an M&V Approach

The four M&V options can be applied to almost any type of ECM. However, the rules-of-thumb listed below generally indicate the most appropriate M&V approach for an application.

Option A can be applied when the most critical M&V issue is identifying the potential to generate savings, including situations in which:

- The magnitude of savings is low for the entire project or a portion of the project to which Option A can be applied.
- The risk of not achieving savings is low or ESCO payments do not need to be directly tied to actual savings.

Option B, retrofit isolation, is typically used when any or all of these conditions apply:

- For simple equipment replacement projects with energy savings that are less than 20% of total facility energy use, as recorded by the relevant utility meter or sub-meter
- When energy savings values per individual measure are desired
- When interactive effects are to be ignored or are estimated using estimating methods that do not involve long-term measurements
- When the independent variables that affect energy use are not complex and excessively difficult or expensive to monitor
- When sub-meters already exist that record the energy use of subsystems under consideration (e.g., a 277 V lighting circuit, a separate sub-meter for HVAC systems)

Options C, billing analysis, is typically used when any or all of these conditions apply:

- For complex equipment replacement and controls projects
- When predicted savings are relatively large (greater than 10% to 20%) as compared with the energy use recorded by the relevant utility meter or sub-meter
- When energy savings values per individual measure are not desired

- When interactive effects are to be included
- When the independent variables that affect energy use are complex and excessively difficult or expensive to monitor.

Option D, calibrated simulation, is used in situations similar to Option C, or in addition when any or all of these conditions apply:

- When new construction projects are involved
- When energy savings values per measure are desired
- When Option C tools cannot cost-effectively evaluate particular measures or their interactions with the building when complex baseline adjustments are anticipated

5.2.2 M&V Planning Tool

The M&V Planning Tool is an iterative exercise designed to assist in the development of custom M&V approaches for individual projects. The Tool uses a five-step process that requires the development of a custom list of objectives and constraints that relate to measurement and verification of savings. The process considers both project level and ECM-specific objectives and constraints, which must be prioritized during the evaluation process. The steps described below correspond to the step numbers on the flowchart shown in Figure 5-1.

5.2.2.1 Step 1: Develop a list of project and ECM-level objectives and constraints that relate to measurement and verification of savings.

Some typical objectives and constraints for M&V are listed below. A custom list should be developed for the specific project based on key topics that will affect the M&V plan for the project and/or ECMs.

Typical Objectives

- Track energy savings through utility metering
- Verify energy performance continuously
- Verify energy performance annually
- Track post-retrofit consumption
- Track performance of individual measures
- Adjust baseline for changes
- Maximize infrastructure by using least-cost M&V option

Typical Constraints

- Historical utility data not available
- Lack of dedicated utility meters
- High degree of Interaction between ECMs
- ECMs scope affects a very small portion of overall utility baseline

It is appropriate to identify objectives and constraints that may apply, but enough information is not yet available, as these items may be significant to the M&V approach selected. These uncertain items should be clarified as early in the project as possible if they drive the approach selected.

As shown in Table 5-3, a priority (high, medium, or low) can be assigned to each objective and constraint identified to help with the evaluation. High-priority objectives and constraints have the strongest influence on M&V selection and should be considered most important in the evaluation.

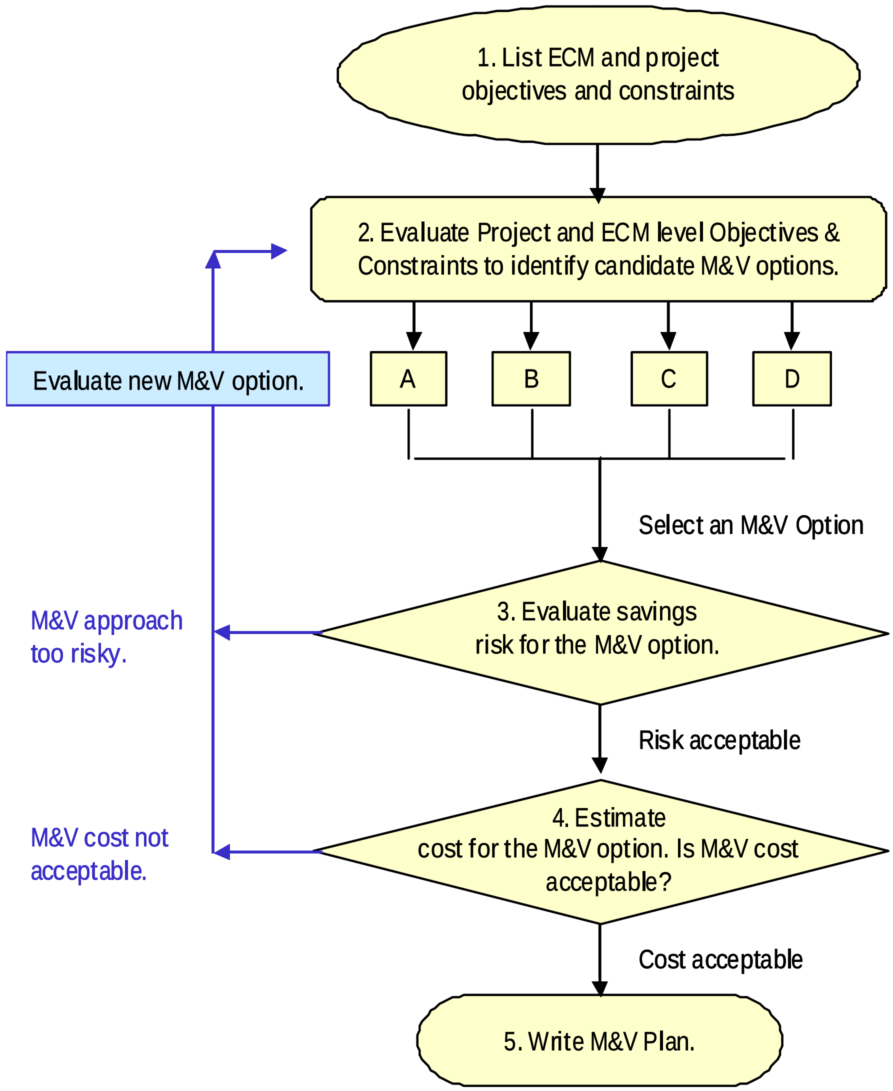


Figure 5-1 M&V Planning Flowchart

Step 2: Select an M&V option for evaluation (Options A, B, C, or D).

Project and ECM-level objectives and constraints must be evaluated to identify the most appropriate M&V option. The nature of the objective or constraint will either lend itself to or rule out specific M&V options, including a retrofit isolation approach (Options A and B), a whole-building utility data analysis (Option C), or a calibrated simulation (Option D).

One should determine if a single M&V Option can be used and is desirable for the entire project or if a more custom M&V approach is required for the proposed set of ECMs. If one of the important project-level objectives or constraints is not met, another M&V option should be selected for evaluation. If none of the M&V Options can satisfy project level objectives and constraints, an appropriate M&V Option should be selected for the first ECM and the evaluation process should be completed following Steps 3 through 5. This process should be followed until an M&V approach is defined for ECM.

Table 5-3 Example M&V Considerations Matrix

Objective or Constraint	ECM or Project Level	Priority	Project Specific Objectives and Constraints (List the Ones That Directly Affect the M&V Approach for the Project)	Retrofit Isolation Approach (Options A and B)	Utility Bills Comparison Approach (Option C)	Calibrated Simulation Approach (Option D)
Objective	Project	High	Ensure equipment performance for life of contract	X		
Objective	Project	Medium	Want to track energy savings at utility meter(s)		X	
Constraint	Project	Medium	Historical utility data pertinent to project scope are available		X	X
Objective	Project	Medium	Verify energy performance periodically	X	X	X
Objective	Project	Low	Maximize infrastructure improvement by implementing the most cost-effective M&V option	X		
Objective	HVAC	High	Ensure long-term equipment performance	X		
Objective	HVAC	High	Ensure savings for the duration of the contract (persistence)	X	X	
Objective	Lighting	High	Maintain lighting levels	X		
Objective	Lighting	Medium	Quantify savings through measurements	X		
Constraint	Windows	Medium	High interactive effects		X	X
Objective	Windows	Medium	Quantify savings from ECM			X

5.2.2.2 Step 3: Evaluate the savings risk associated with the selected M&V option(s).

To perform this exercise, a custom list of risk elements should be developed based on project and ECM specifics. The Responsibility Matrix in Chapter 3 provides a compete discussion of risk elements, how responsibilities should be allocated, and how they impact M&V plan selection.

Typical risk elements for ESPC projects include:

- Operating hours
- Environmental/process loads
- User participation
- Weather

- Equipment performance
- Major changes to the facilities
- Savings risk associated with the performance of O&M, repair, and replacement

5.2.2.3 Step 4: Estimate costs for the M&V option.

If one M&V option has been selected for all ECMs, the cost of using this M&V option in relation to savings risks should be estimated. If a custom approach is being followed for individual ECMs, Steps 3 and 4 should be repeated for each ECM until an M&V option has been associated with each ECM. Then, the cost of using the selected M&V options should be estimated.

If the M&V requirements and the savings risk fail to justify the M&V expenses one should return to Step 2.

5.2.2.4 Step 5: Write the M&V plan.

If all the M&V requirements are met and the savings risk justify the M&V expenses, proceed with the development of the M&V plan for the project.

5.3 COST AND RIGOR

In general, the more rigorous the M&V, the more expensive it will be to determine energy savings. The factors that typically affect M&V accuracy and costs (some are interrelated) are listed below.

- Level of detail and effort associated with verifying baseline and performance period surveys
- Sample sizes (number of data points) used for metering representative equipment
- Duration and accuracy of metering activities
- Number and complexity of dependent and independent variables that are metered or accounted for in analyses
- Level of engineering required to conduct analyses
- Availability of existing data collecting systems (e.g., energy management systems)
- Contract term
- Level of accuracy needed in energy savings analyses

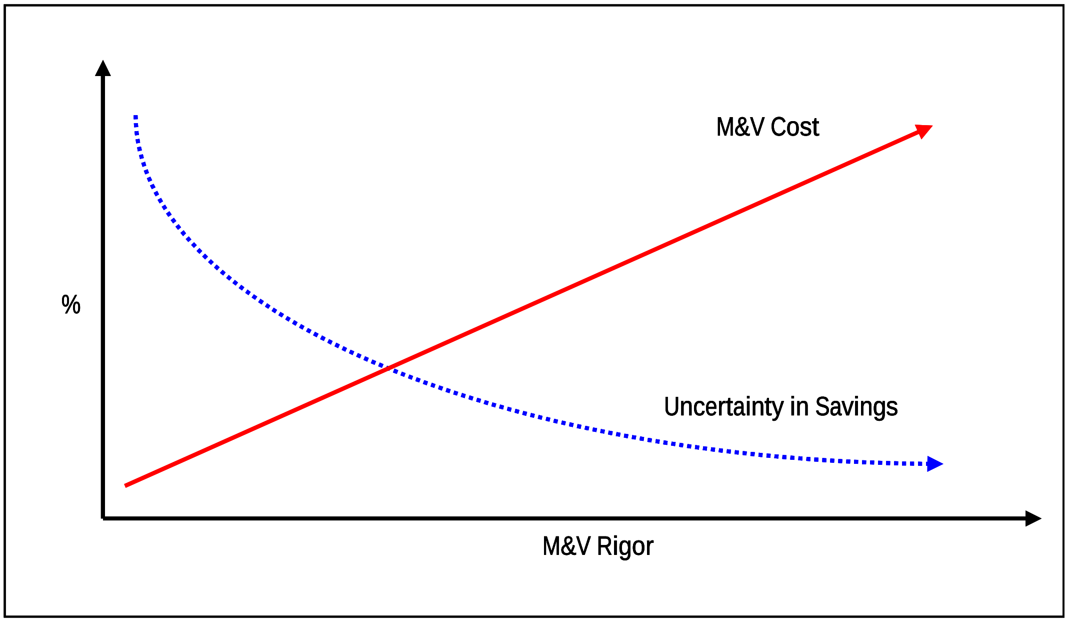
5.3.1 Balancing Cost and Rigor

One of the most challenging aspects of M&V is providing adequate accuracy while ensuring that M&V costs are reasonable. As shown in Figure 5-2, the incremental value of the information obtained from additional M&V will at some point be less than the cost to obtain it. Unfortunately, there is no easy way to define this point and one must rely upon judgment and experience to determine what is cost-effective and what is not.

A few strategies for keeping costs down while maintaining technical rigor include:

- Use extensive metering in the baseline period and stipulate values over which the ESCO has no control.
- Verify key performance items using periodic rather than continuous data collection to reduce data collection and management issues.
- Rely upon existing instrumentation, energy management systems, and energy management behavioral practices wherever possible.
- Engage a third-party M&V expert to assist in the development of the measurement and verification plan to ensure key agency interests are protected and costs are minimized.

Figure 5-2 The Law of Diminishing Returns for M&V



5.3.2 Savings Calculations

The savings calculation approach usually depends on the M&V method selected for the measure. If long-term monitoring is not used in the M&V technique, the ESCO and the agency must accept that the agreed-upon savings will not equal the savings that would be determined through a process that involves rigorous analyses and measurements. If important values are estimated, both parties should understand that the savings determination will tend to be less accurate than if measurements were used to determine the values.

5.3.3 M&V Costs

The M&V effort should be scaled to the value of the project so that the value of the information provided by the M&V activity is appropriate to the value of the project itself. Rule-of-thumb estimates put overall annual M&V costs at 1% to 10% of typical project cost savings. Often, some ECMs will entail greater M&V costs, but the overall M&V costs for the project are balanced by other ECMs that do not require substantial annual activities.

For a Super ESPC project, M&V are reported into two categories: initial and annual M&V expenses. The initial M&V costs may include metering or instrumentation required to perform the M&V activities, and is delineated by ECM on Task-Order Cost Schedule TO-2 (Implementation Price by Energy Conservation Measure). The performance-period M&V expenses included for the entire project are included on Task-Order Cost Schedule TO-3 (Post-Acceptance Performance Period Cash Flow). M&V cost breakouts should be requested and evaluated to ensure that costs are in line with the scope of work outlined in the M&V Plan.

5.4 UNCERTAINTY

Any statement of measured savings includes some degree of uncertainty. Since no instrument can be 100% accurate, all measurements contain some error or difference between the true and observed value. In addition, energy savings are typically based on measured values, which to some extent are estimates. As with all estimates, there will be some uncertainty in the reported numbers. The goal for each project is to reduce the uncertainty in the reported savings values, which is accomplished by limiting the errors in the measurements and analyses conducted.

Calculating the uncertainty in the estimated savings is not required by Super ESPC, but this uncertainty is often estimated by the ESCO in order to set the overall level of savings guarantee for each ECM. Including the uncertainty in calculated savings values provides a more meaningful statement of savings. Uncertainty is typically proportional to the complexity of the ECM.

Uncertainty at the project level can be broken down into four general types: measurement, sampling, estimation, and modeling. For any given project, the project error is calculated from theses four uncertainties. Projects often do not contain one or more of the four components; however, in a hypothetical project that contains all four components, the total project uncertainty (standard error) would be calculated by taking the square root of the sum of the squares of the individual standard errors of the components, as below:

$$SE_{project} = \sqrt{(SE_{Measurement})^2 + (SE_{Sampling})^2 + (SE_{Stipulation})^2 + (SE_{Modeling})^2}$$

The following sections discuss the sources of these errors and the way that these sources can be minimized in a Super ESPC project.[26]

5.4.1 Measurement

Measurement uncertainty is due to metering equipment inaccuracies. For example, the specifications for a meter may indicate that it is accurate to within ± 5%, meaning that any reading taken the meter may be up to 5% off in either direction. Additional error in measurements may be introduced if an instrument is not properly calibrated or if it is applied under inappropriate conditions. Data management can also introduce errors through omitted, adjusted, or lost data.

For an M&V plan to be successful, the sensors used for baseline and performance period measurements must meet minimum accuracy requirements for the application and must be

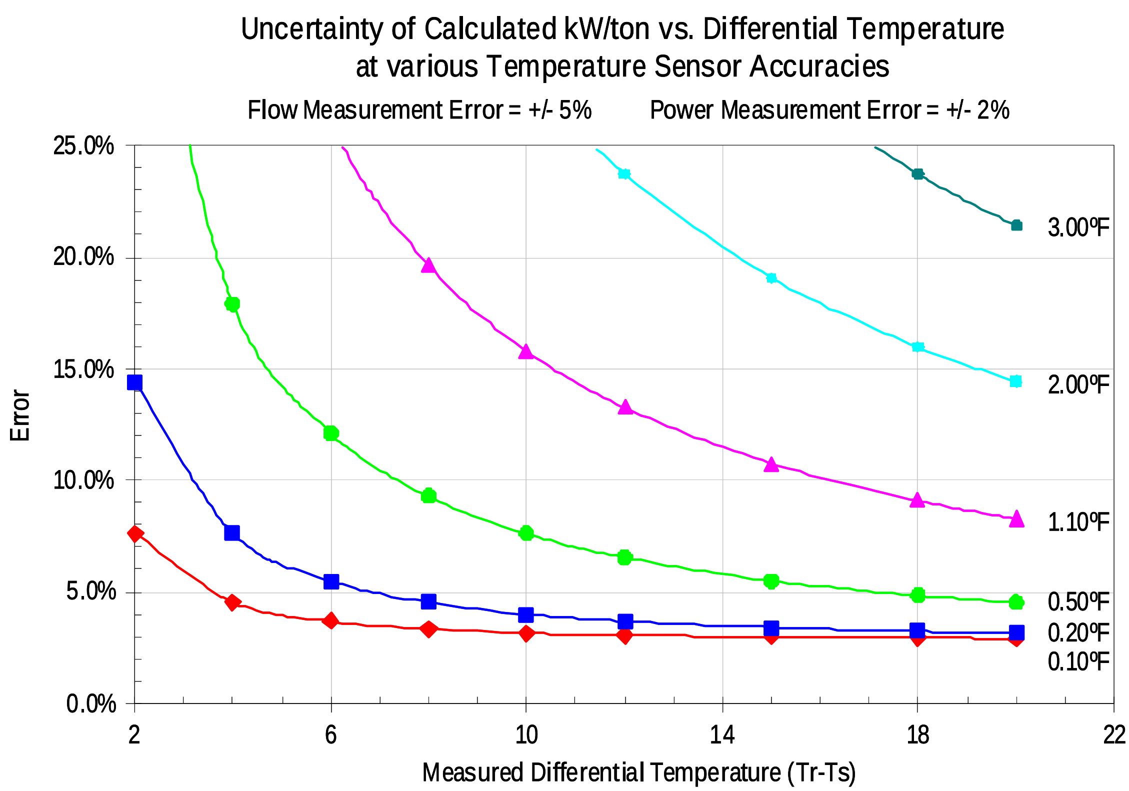
[26] Additional information on these topics is contained in ASHRAE Guideline 14 Section 5.2.11 and IPMVP Appendix B.

properly calibrated. If the accuracy of any instrument is less than suitable, the measurements may introduce unacceptable levels of error into the energy calculations.

Instrumentation accuracy requirements should be sufficient to ensure that overall energy and cost estimates are reasonable. Although error analysis is not required by Super ESPC projects, it is important to keep in mind that the inaccuracies introduced by the instrumentation will likely be the greatest source of uncertainty in calculated savings.

For example, in a chiller project, the most important measurements are the chilled water temperatures which are used to determine load. The impact of sensor accuracy on predicted kW/ton values is shown in Figure 5-35-3.

Figure 5-3 Example Impact of Sensor Accuracy on Calculations[27]



Tips for reducing measurement error:

- Determine and prescribe the needed accuracy for measurement equipment.
- Ensure that the measurement equipment has been recently calibrated.
- Specify data management strategies, including periodic checks and back-up procedures.

[27] Analysis provided by Scott Judson.

5.4.2 Sampling

Sampling uncertainty occurs when measurements are taken on a sample of the affected equipment and the results extrapolated to the entire population of the equipment. For example, it may not be economically feasible to monitor the hours on every fixture in a building lighting retrofit. Often, a sample is monitored, and the results applied to the remainder of the lighting population. Sampling uncertainty is calculated from the standard deviation of the sampled results. When the standard deviation is large, the uncertainty is also large. A detailed discussion on sampling can be found in Appendix B.

Tips for reducing sampling error:

- Assign homogeneous usage groups based on similarities in equipment performance or operating characteristics.
- Use statistical sampling strategies described in Appendix B.
- Use sample sizes that meet a confidence of at least 80% and a precision of 20%.
- Ensure that the measured data meet statistical requirements by calculating the actual coefficient of variation (Cv) from the measurements.
- Use a conservative approach in selecting original sample sizes by using a high Cv, typically greater than 0.5, especially for populations that are know to contain variations. This will increase the initial sample size, but reduce the risk of under-sampling.

5.4.3 Estimating

Estimates have to be made when values are necessary to complete a calculation, but the values cannot be measured directly. When engineering estimates are used in lieu of actual measurements, uncertainty is introduced. This uncertainty itself must often be estimated based on the expected accuracy of the estimated values. For example, the efficiency of a boiler may be estimated rather than measured directly. The estimate would be based on the type and age of the boiler, and may result in an estimated stipulation error of ± 20% (e.g., 75%, between 60% and 90%). If a building engineer who is familiar with the boiler gives additional operational information about the boiler, the uncertainty may be less, such as ± 10% (e.g., 75%, between 67.5% and 82.5%).

Tips for reducing estimating error:

- Use measured values wherever possible, especially for parameters that contribute to a high percentage of project savings.
- Use the manufacturer's original specifications or industry-accepted performance curves to determine performance.
- Use typical meteorological year (TMY) weather data[28] from an applicable site to conduct calculations.

[28] TMY weather data is available from National Oceanographic Atmospheric Administration (NOAA).

- Use observations of building occupant behavior and facility operating and maintenance logs.
- DO NOT use rules-of-thumb, proprietary software/algorithms, guesses at operating parameters, or data from other facilities.

5.4.4 Modeling

Modeling uncertainty is introduced when savings are estimated using engineering or simulation models. The accuracy of any model is based on the ability of the model to account for all variations in energy use by employing the proper analysis techniques, including all relevant variables, and excluding those that are irrelevant.

A tip for reducing modeling error is to request the ESCO provides calculations in electronic format, and to have a qualified third-party reviewer closely analyze the savings calculations.

Section 6 Incorporating M&V in Super ESPCs—Key Submittals

This section provides an overview of measurement and verification (M&V) submittals required in each phase of a Super Energy Savings Performance Contract (ESPC) project. The key submittals related to M&V in a Super ESPC project are outlined in Table 6-1 and discussed below. In this table, the name of the Super ESPC submittal or item is shown in italics. Some of the terminology used specifically in Super ESPC projects is defined in Table 6-2.

Table 6-1 Super ESPC Submittals Related to Measurement and Verification

Required M&V Item	Location(s)	Timing for Development[29]
M&V Approach	*Preliminary Assessment*	Initial project scoping
Risk and Responsibility Matrix	*Preliminary Assessment* *Final Proposal*	Initial project scoping, prior to *Notice of Intent to Award* During *Investment Grade Audit*
M&V Plan and Savings Calculation Methods	*Final Proposal*	After *Notice of Intent to Award* and during *Investment Grade Audit*
Commissioning Approach	*Final Proposal*	During *Investment Grade Audit*
Commissioning Plan	Separate submittal	After approval of *Design & Construction Package*
Commissioning Report	Separate submittal	Prior to *Project Acceptance*
Post-installation Report	Separate submittal	Prior to *Project Acceptance*
Annual Reports	Separate submittal	60 days after anniversary date of *Project Acceptance*

Table 6-2 Super ESPC Project Terminology

Project Phase	M&V Submittal	Term Used
Project Development	M&V Plan (Final Proposal)	Proposed Savings
Project Acceptance	Post-Installation Report	Expected Savings
Performance Period	Annual Reports	Verified Savings

6.1 M&V APPROACH

The first M&V-related item received on a Super ESPC project is the ECM Performance Measurement section of the Preliminary Assessment. This section provides a general description of the M&V Plan proposed for the project. Although very little detail is included in this section, it is important that the agency and the ESCO agree on the general M&V approach(s) to be used prior to starting the Investment Grade Audit (IGA). The M&V method(s) chosen can have a dramatic effect on how the baseline is defined, determining what activities are conducted during the IGA.

[29] Detailed information on DOE's Super ESPC process is available at http://www1.eere.energy.gov/femp/financing/superespcs.html.

6.2 ESPC RISK AND RESPONSIBILITY MATRIX

A project-specific Risk, Responsibility and Performance Matrix is required for Super ESPC projects. It is first presented in the Preliminary Assessment and is finalized in the Final Proposal.

The Responsibility Matrix details risks and responsibilities that should be considered when developing performance contracts, especially the verification requirements of these contracts. This Responsibility Matrix was developed to help identify the important project risks, assess their potential impact, and clarify the party responsible for managing the risk.

The final agreed-upon Responsibility Matrix will greatly influence the measurement and verification approach(s) used in the project, which must reflect the allocation of responsibilities. Additional discussion of the Responsibility Matrix is included in Chapter 3.

6.3 MEASUREMENT AND VERIFICATION PLAN

The project-specific M&V Plan is included in the ECM Performance Measurement section of the Final Proposal. The M&V Plan is the single most important item in an energy savings guarantee, as it defines how savings will be calculated and specifies any ongoing activities that will take place during the contract term. The M&V Plan details the proposed Year 1 energy and cost savings. The ESCO prepares the project-specific M&V Plan and submits it to the federal agency for review and approval.

Super ESPC projects are required to use the M&V Plan and Savings Calculation Methods Outline described in Appendix C.

Details required in the Measurement and Verification Plan are discussed in Section 7 of this document.

6.4 COMMISSIONING APPROACH, PLAN, AND REPORT

The Commissioning Approach for each ECM is included in the ECM Performance Measurement section of the Final Proposal. The Commissioning Approach outlines the expected commissioning activities and identifies roles and responsibilities of the ESCO and the federal agency.

The project-specific Commissioning Plan is developed after the engineering design is finalized and the Design and Construction Package has been approved by the agency. The Commissioning Plan finalizes the Commissioning Approach outlined in the Final Proposal and addresses each ECM with specific steps that will be taken during the commissioning process.

Once commissioning activities have been completed and documented per the approved Commissioning Plan, the Commissioning Report is submitted. This report details the inspections and performance tests implemented, along with the results of these inspections and tests, to ensure that the systems were installed and performing properly. It also verifies systems and equipment are operating as intended and according to design intent.

Information on commissioning can be found in Section 7 of this document.

6.5 POST-INSTALLATION REPORT

After the commissioning activities have been completed, the post-installation verification activities defined in the M&V Plan are conducted. The results of the post-installation verification activities are presented in the Post-Installation Report, which is delivered by the ESCO prior to project acceptance. This report also documents any changes in the project scope and energy savings that may have occurred since the Final Proposal, and reports the expected Year 1 energy and cost savings.

Super ESPC projects are required to use the Post-Installation Report Outline shown in Appendix C. Information on post-installation is included Section 2.2.5.

6.6 ANNUAL INSPECTIONS AND REPORTS

Each year during the performance period, typically just after the anniversary of the project's acceptance, the contractor submits an Annual Report. The report documents the execution and results of the activities prescribed in the M&V Plan (measurements, savings calculations) and reports the verified Year 1 energy and cost savings. The report also describes O&M activities conducted during that performance period, as well as any identifying items that may require additional follow-up.

For Super ESPC, M&V needs to show only that the overall cost savings guarantee has been met, and not that the predicted savings for each ECM have been achieved.

The verified savings values presented in the Annual Report determine if the annual savings guarantee has been met, and if any true-up of payments is required. As stipulated in the contract or Task Order, the federal agency may use the annual report to reconcile payments made to the ESCO for previous billing periods if previous payments were based on expected savings that then need to be trued-up to reflect verified savings. The estimates in the report may also be used as the basis for subsequent payments.

Super ESPC projects are required to use the Annual Report Outline shown in Appendix C.

Section 7 M&V Plan Details

The Measurement and Verification (M&V) Plan is a document that defines project-specific M&V methods and techniques that will be used to determine savings resulting from a specific performance contracting project. The plan may include 1) a single option that addresses all the measures installed at a single facility, or 2) several M&V options to address multiple measures installed at the facility.

In addition to providing accurate and conservative methods to calculate energy savings, a good M&V Plan is clear, consistent, and repeatable. In a long-term contract, it is very important to ensure that all assumptions, procedures, and data are recorded properly so they may be easily referenced and verified by others. The data included should be sufficient for a third party to implement or verify the M&V procedures.

M&V activities include site surveys, energy measurements, metering of key variables, data analyses, calculations, quality assurance procedures, and reporting. All of these key components need to be adequately detailed in the M&V Plan.

The project-specific M&V Plan must be submitted and approved by the federal agency before M&V activities begin. In some cases, the agency will specify an approach in the RFP, while in other cases the energy service company (ESCO) will propose a site-specific plan for approval. Final resolution of M&V and other project issues are left to the discretion of the federal agency, although the details of the M&V Plan can be a highly negotiated item.

Contracts implemented under DOE's Super Energy Savings Performance Contract (Super ESPC) are required to follow the M&V Plan and Savings Calculation Methods Outline included in Appendix C. This outline was developed through an industry-government working group and has been incorporated into the Super ESPC contract. The project-specific M&V Plan includes project-wide items as well as details for each energy conservation measure (ECM) (see Section 2.2.6).

In general, the contents of a project-specific M&V Plan should:

- Provide an overview of the ECM and verification activities, including:
  - State the goals and objectives of the verification activities
  - Define the M&V option and techniques to be used for each measure
  - Identify the key physical characteristics of the facility, system, and ECM to be installed
  - Define the critical factors that affect energy consumption of the system or ECM
- Adequately define the baseline conditions, including:
  - Identify the key baseline performance characteristics of the system or ECM, such as lighting intensities and temperatures

  - Define baseline operating conditions, such as loads and hours of operation
- Detail all measurements, data analyses procedures, algorithms, and assumptions
- Define all performance period verification activities, including:
  - Specify the parameters to be measured, period of metering, accuracy requirements, calibration procedures, metering protocols, sampling protocols, and archiving requirements
  - Explain requirements for agency witnessing of M&V activities
- Detail the schedule for periodic M&V reports and procedures
- Describe procedures and details for annual inspections
- Describe O&M reporting requirements by agency and ESCO (See Section 9 of this document).
- Detail how savings will be calculated, including:
  - Provide rationale and procedures for any baseline or reporting period energy adjustments anticipated
  - Detail how interactive effects will be handled

The first step in defining a project-specific M&V Plan involves selecting an appropriate M&V approach or approaches. This process is discussed in detail in Chapter 5 and includes evaluating project-wide and ECM-specific objectives and constraints, assessing the viability of various M&V options, ascertaining savings risks, and evaluating implementation costs.

The following sections discuss and provide insight into the key areas covered by an M&V Plan. Procedures for reviewing M&V Plans for content and quality are detailed Section 10 of this document, and review checklists can be found in Appendix E. Issues and requirements associated with specific technologies are described in Chapter 8.

7.1 DEFINING THE BASELINE

Since energy savings must be determined by comparing energy use before and after a retrofit, the characterization of the pre-retrofit or baseline conditions is critical. Defining the baseline consists of identifying the performance and operating factors that influence energy consumption, and determining their values through observations and measurements.

Regardless of the M&V option or method used, the baseline conditions for all projects and ECMs must be adequately defined. Typically, the ESCO will define the baseline conditions during the Investment Grade Audit, but the federal agency may define baseline conditions.

The purpose of establishing the baseline conditions is to:

- Define the baseline sufficiently for purposes of calculating savings
- Document the baseline conditions in case operational changes occur after ECM installation that mandate adjustments to the performance period baseline energy use

Baseline conditions include physical, operational, and energy use data on the facility and systems. Baseline conditions are typically determined through surveys, inspections, and spot and short-term metering activities. Typically, pre-installation metering is conducted for a period of time required to capture all operating conditions of affected systems and/or processes.

Physical conditions that should be documented include equipment inventories, locations, nameplate data, system design features, and building occupancy. The key operational conditions include control strategies, set points, operating schedules, condition of equipment, loads, maintenance procedures used, peripheral equipment conditions, and weather. Energy use data that constitute the baseline may include utility billing data, sub-metered system data, and utility rate structures.

Although only a portion of a facility's systems may be included in the ESPC project, it may be appropriate to document the site conditions for other key energy using systems. This is especially true if a whole-building M&V approach (Option C or D) is being used. Often, changes outside the scope of the ESPC project at a large facility can affect the overall energy consumption at a site and may warrant an adjustment, as discussed in Section 7.2.

7.2 ADJUSTMENTS

As indicated in Chapter 2 and the basic equation used to determine savings shown below (Equation 7-1), adjustments are sometimes required to account for changes unrelated to the ECM that affect energy use. Such adjustments may account for changes in weather, occupancy, or other factors between the baseline and performance periods.

Equation 7-1: General Equation Used to Calculate Savings

$$Savings = (Baseline \quad Energy - Post \quad Installation \quad Energy) \pm Adjustments$$

The purpose of adjustments is to express both baseline and post-installation energy under the same set of conditions. The modifications to the savings can be further distinguished as routine and non-routine adjustments, as shown in Equation 7-2.

Equation 7-2: Expanded Equation Used to Calculate Savings

$$\begin{aligned} &Savings = (Baseline \quad Energy - Post \quad Installation \quad Energy) \\ &\pm Routine \quad Adjustments \pm Non-Routine \quad Adjustments \end{aligned}$$

7.2.1 Routine Adjustments

Routine adjustments are used to account for expected variations in independent variables and energy use. These adjustments often use regression analysis to correlate and adjust energy use to independent variables such as weather, but simple comparisons may also be employed. Routine adjustments are used to normalize energy use as a function of one or more independent parameters such as temperature, humidity, or meals served.

Normalizing energy savings to a prescribed set of conditions is a very important technique used in ESPC projects. Using a fixed set of conditions for both the baseline and performance period cases, such as average weather conditions and the corresponding cooling load profile, allows the risks associated with these operational factors to be reduced.

Alternatively, baseline and performance period conditions could be normalized to either baseline or performance period conditions. If performance period conditions are used to adjust the baseline case, the savings calculated will estimate the actual avoided energy use for that period.

One of the key assumptions made when normalizing savings is that the performance period energy use will have a predictable relationship to the independent variables to be standardized. The baseline model will be completely defined in the contract, but the performance period model will need to be developed from measured data collected during the performance period. Typically, a valid baseline model indicates that a similar performance period model can be successfully developed.

Once the baseline and performance period models of the equipment's energy consumption and the parameter(s) are established and validated, the standardized values of the independent parameters can be used to drive the both models and calculate savings.

Therefore, a project-specific M&V Plan should identify critical independent variables, explain how these variables will be measured or documented, and discuss how they will be used in the empirical models. Additionally, assumptions and mathematical formulas used in the M&V Plan must be clearly stated, and the validity of any mathematical model used should be verified. The verification strategies discussed in Section **Error! Reference source not found.** can be applied to any mathematical model.

7.2.2 Non-Routine Adjustments

Non-routine adjustments are used to compensate for unexpected changes in energy driving factors, such as facility size, operating hours, and facility use. These factors must be monitored for change to ensure that they are not affecting the performance of the energy conservation measure. Tracking these factors is primarily a concern for projects using whole-building options (Options C & D). Option A approaches typically avoid these types of adjustments as many of the factors that could change are stipulated. If future changes are expected, the M&V Plan should incorporate methods for making these non-routine adjustments.

7.3 INTERACTIVE EFFECTS

It is commonly understood that ECMs and energy systems interact with one another. Reduced lighting loads, for example, can reduce air conditioning energy consumption (a cooling bonus), but increase heating consumption (a heating penalty). Whole-building M&V approaches such as building simulation or utility billing analysis account for these types of interactive effects, whereas retrofit isolation M&V approaches do not.

When using retrofit isolation M&V Options A and B, careful consideration must be given to dealing with interaction between ECMs. One must properly account for interactive effects and avoid double-counting of savings, which can occur inadvertently if interactions are not carefully considered.

For example, if the lighting retrofit mentioned above is accompanied by a chiller replacement, care must be taken to account for the reduced cooling loads on both the new and existing chillers due to the change in lighting. In addition, the cooling bonus should be based on the efficiency of the new chiller.

In general, the possibility of double-counting energy savings can be reduced by considering one ECM at a time. The later ECMs should start (the baseline condition) from the performance period condition of the previous ECMs. For related ECMs, such as lighting efficiency and lighting controls, double-counting can sometimes be avoided by using a single equation to determine savings from both measures.

Methodologies for determining some of the more common interactions, such as lighting and HVAC, have been developed (see Section 11.1). However, detailed relationships between many dissimilar but interactive ECMs are not known, and the methods for measuring interactive effects are not cost-effective for many applications. For projects using retrofit isolation approaches (Options A or B), one of three approaches can be taken to account for savings associated with interactive effects between ECMs. These approaches are as follows:

- Ignore interactive effects.
- Use mutually agreed-upon values that are based on the site-specifics of the building and HVAC equipment types. The values can be developed on the basis of computer model simulations for typical building conditions or assigned on the basis of available information for typical buildings.
- Develop a site-specific method to measure and estimate interactive effects. The federal agency and/or ESCO will need to agree on the merit and reasonableness of the proposed approach, which may include directly measuring the effects.

7.4 METERING[30]

To determine energy savings, some measurement processes need to be conducted to identify the pre-retrofit and post-retrofit conditions. These measurements typically include energy consumption and energy-related variables. Metering issues that should be considered in preparing a project-specific M&V Plan are discussed below.

A project-specific M&V Plan should demonstrate that any metering and analysis will be done in a consistent and logical manner and with a level of accuracy acceptable to all parties. Metering and monitoring reports must specify exactly what was measured, how and when the measurements were made, what meter or meters were used, and who conducted these measurements. Any metering protocols that will be followed must be specified.[31]

Issues covered below include types of meters, meter accuracy and calibration, metering protocols, duration of metering, and the use of samples.

[30] More information on metering is available throughMetering Bset Practices: A Guide to Achieving Utility resource Efficeincy, Federal Energy Management Program, October 2007.

[31] Metering protocols are standardized procedures developed for measuring physical characteristics and metering specific types of equipment. For example, ASHRAE Guideline 14 Annex E describes standard procedures for measuring physical characteristics, including power, temperature, flow, pressure, and thermal energy and describes standards for measuring the performance of chillers, fans, pumps, motors, boilers/furnaces, and thermal storage.

7.4.1 Equipment

Many tools are available which help collect and analyze system-wide HVAC data, control data, and lighting performance data. Data may include power (kW), energy (kWh), and operating parameters such as temperature, humidity, pressure, flow rates, status, and lighting levels. Data can be collected through one-time measurements or can be recorded in user-defined intervals. Prices, applications, and complexity of these tools vary.

For data collection, storage, and reporting, there are two general categories of metering equipment for M&V activities: data loggers and energy management systems.

Data loggers range from simple battery-powered portable devices to more complex tools that can collect inputs from up to 30 transducers. The most simple portable data loggers collect information about a single variable (such as light fixture on/off status or amp draw from a motor). Others can capture multiple inputs (such as voltage, power factor, and amperage) and perform some calculations. Portable data loggers tend to be inexpensive per unit, but are more limited in applications. The downloading of data is usually done manually off site through a connection to a personal computer, although modem connections are sometimes used. Battery-powered portable loggers can offer non-intrusive monitoring within an occupied area, are relatively simple to use, and are inexpensive. More complex data loggers can collect information from a range of different inputs, conduct some analyses, prepare reports, and, typically through modems, download information for remote data collection. Permanently installed data loggers tend to be relatively expensive (when transducer and installation costs are included) and, if hard-wired, not very portable, which is an issue when only short-term measurements are required.

Energy management systems are used for controlling systems. These would logically be an excellent option since such systems are often already in place and have data collection, trending, and computing capability; however, caution should be exercised, as many systems are not designed for data storage and reporting, and many operators are not familiar with M&V requirements.

7.4.2 Sensor and Meter Accuracy and Calibration

Before any data are collected, all sensors and meters should be reviewed to ensure that they are appropriate for the application. The accuracy of the device used to collect data can significantly affect the validity of the data collected and increase the level of error that is introduced in any calculations. Often, measurement error will be the primary source of uncertainty in a savings value. Using high-quality sensors for gathering key data can help increase the accuracy of savings estimates. Measurement uncertainty is discussed in detail in Section 5.4.

Equipment accuracies provided by the manufacturer are meaningful only if the equipment is in calibration. Sensors and meters used to collect M&V data should be calibrated to known standards (such as those of the National Institute of Standards and Technology). Forms indicating that calibration has been conducted are a required part of the M&V reports.

For the calibration to be valid, the equipment used to calibrate the sensors and meters must be of a greater accuracy than the sensors or meters themselves. Calibration methods for a variety of applications are included in ASHRAE Guideline 14.

7.4.3 Metering Duration

The duration of metering and monitoring must be sufficient to ensure an accurate representation of the amount of energy used by the affected equipment both before and after project installation. The appropriate measurements should be taken within a specified and representative time period. These measurements can then be used to determine time-of-use and annual energy consumption. The time period of measurement must be representative of the long-term (i.e., annual) performance of the ECM or system. For example, lighting retrofits in a 24-hour warehouse that is operated every day of the year may require only a few days of metering. However, a chiller retrofit may require metering throughout the cooling season or perhaps for 1 month each season of the year.

The required length of the metering period depends on the type of ECM(s) or system. Some common scenarios are discussed below.

- For equipment that operates according to a well-defined schedule under a constant load, such as a constant-speed exhaust fan motor, the period required to determine annual savings could be quite short. In such a case, short-term energy savings can be extrapolated easily to the entire year.
- If the project's energy use varies across both day and season, as with air-conditioning equipment, a much longer monitoring period may be required to characterize the system. In a case like that, long-term data are used to determine annual energy savings. When the metering is complete, the limits of the model used to characterize the system must be defined. For example, if data were taken on the chiller system only when the outside air temperature ranged from 50°F to 70°F, then the resulting chiller model would probably be valid only within the model limits of 50°F to 70°F.
- For some types of projects, metering time periods may be uncertain. For example, there is still controversy over how long lighting operating hours must be measured in office buildings to determine a representative indication of annual operating hours. In these situations, an agreement is required between the project parties to determine the appropriate measurement period and accuracy level for the ECM(s) or systems under consideration. For lighting projects, 3 weeks of monitoring during non-holiday periods is typically effective.
- For some projects, the metering time period can be reduced by forcing a system to go through all of its operating modes in a short period of time. For example, a variable-speed drive ventilation system that is controlled by outside air temperature may require months of data collection to capture a full range of performance data. However, if the control system were over ridden to force it to operate in various modes, the data collection might take only a day. This approach should be used with caution, as additional monitoring may be required to determine the system's relationship to independent variables.

7.4.4 Sampling

Sampling techniques should be used when it is unrealistic to monitor every piece of equipment affected by a retrofit. The sampling procedures outlined in Appendix B provide guidance on selecting a properly sized random sample of equipment for monitoring energy-related factors such as operating hours, load factor, or kW. The measurements, taken from a sample of equipment, can then be used to estimate the energy-related factors for the entire population.

A successful sample will be sufficiently representative of the population to enable one to draw reliable inferences about the population as a whole. The reliability with which the sample-based estimate reflects the true population is a function of specified statistical criteria, such as the confidence interval and precision level, used in the sample design. The reliability of a sample-based estimate can be computed only after the metered data have been collected. Before collecting the data, one cannot state the level of reliability that a given sample size will yield. However, one can compute the sample size that is expected to be sufficient to achieve a specified reliability level. This is done by using projections of certain values and criteria in the sample size calculations.

Based on the data gathered for a selected period of time, the sample size required may be reduced or increased. If the projections are too conservative, the estimate will exceed the reliability requirements. If these projections prove to be overly optimistic, then the reliability of the estimates will fall short of the requirements, necessitating additional data collection to achieve the specified reliability level. This method of using projections to calculate the necessary sample size is the one adopted for these guidelines.

7.5 ENERGY COSTS

The goal of ESPC is to reduce energy, water, and/or operations and maintenance (O&M) costs at federal facilities. The M&V Plan should be designed to provide energy, water, and operating savings information in such a way that cost savings can be reasonably estimated.

For example, energy cost savings will be calculated using energy savings and the appropriate cost per unit of energy saved. In most cases, the unit cost of energy will be based on the servicing utility’s energy rate schedules at the time the project is implemented. The unit cost of energy that will be used in calculating energy cost savings each year during the performance period must be defined in sufficient detail in the contract to allow savings to be calculated using each of the factors that affect cost savings. These factors include items such as (for electric bills) kWh saved, kW saved, power factor, kW ratchets, and energy rate tiers. If the rate uses time-of-use periods, the energy and demand savings may be calculated separately for each time-of-use period. More complex rates, such as demand ratchets, may require additional calculations. The savings calculations are straightforward.

Demand savings may be based on an average demand reduction or a maximum demand reduction. Average reduction in demand, which is typically not equal to the actual reduction in billing demand, is calculated as the kWh savings during the time period in question (usually the utility summer peak period) divided by the hours in the time period. Maximum reduction in demand is typically the reduction in the utility-metered maximum demand under terms and conditions specified by the servicing utility. For example, the billing peak may be based on the maximum building kW load measured in 15-minute intervals and coincident with the utility peak demand period. The maximum demand reduction is usually calculated to determine savings in utility peak demand charges. Thus, if utility demand savings are to be determined, each site must define 1) how the reduction will affect the utility bill and 2) how the demand reduction will be calculated for purposes of payments to the ESCOs.

For performance contracts with cost savings based on peak or billing period load reductions, an M&V method should be selected that provides energy savings data by time-of-use periods corresponding to the facility's rate structure. For example, at a federal prison, the water heating peak load might be 252 kW over a 2-minute averaging period, 228 kW over 15 minutes, or 192 kW using 60-minute time periods of analysis. Considerable error in cost savings estimates are introduced by data that do not correspond to the rate structure (15 minutes, in this case). Thus, it is critical that M&V Plans reflect the effects of time-of-use and block rate schedules. Similarly, if the utility's peak demand period is from 9 am to 5 pm, any demand savings realized outside of these hours will not result in reductions in demand charges.

When determining the value of the energy, caution should be exercised to ensure that a conservative estimate is used that will not overvalue savings. The marginal cost of energy (i.e., the actual cost for the last portion of energy used for each month) should be used, rather than average values. The marginal costs can be determined by reducing the utility usage by 1 kWh or 1 kW, for electricity, and then recalculating the bill. Because there can be many fixed fees, demand charges, and distribution charges, it is important that average values are not used and that only commodity-based charges are included.

The ESCO may propose rates to use, but it is up to the agency to ensure that the correct rates are applied and the arithmetic is correct. At a minimum, the ESCO must provide the unit cost of fuel for each source of savings in the M&V Plan.

7.5.1 Using Escalation Rates

For each project, the ESCO and agency must mutually agree upon both the unit cost of energy for each fuel source and any escalation factors that may be applied during the performance period. Escalation rates are often employed in long-term contracts to estimate the future values of energy more accurately. Although higher values of energy will provide better cash-flow for the project, overvaluing savings is a serious concern that can cause budgetary problems for the agency.

A common source on which to base this rate of change would be the energy price escalation rates projected annually by the DOE Energy Information Administration (EIA). As these rates vary from year to year by region, fuel type, and rate schedule, it can be difficult to condense these variables into one annual average rate for all project sources, which is the preferred approach.

The DOE has created a tool, Energy Escalation Rate Calculator (EERC), which can calculate a single appropriate escalation rate to use over the entire contract term. The EERC uses percentage of base-year cost savings attributable to each fuel in the project, commercial or industrial rate type, project location, and start and duration of performance or contract period. It then retrieves the matching EIA rates and calculates the weighted average escalation rate in real terms (excluding inflation) and nominal terms (including inflation). The default inflation rate, which can be edited, is the long-term inflation rate published annually on April 1 by FEMP for use in life-cycle cost analyses of energy and water conservation and renewable energy projects.

The EERC-calculated average annual escalation rate, when applied to the base-year costs or savings of ESPC projects, results in approximately the same future total amounts over the contract period as do the EIA-projected variable rates, making the EERC rate a reasonable proxy rate for escalating contract payments. EERC can be downloaded from the FEMP website.[32] It is updated on April 1 of each year with the latest EIA energy price data.

Escalation rates for other savings, such as O&M costs, should be determined separately from energy rates, since inflation in labor and material costs may be substantially different from inflation in energy costs

7.6 AGENCY WITNESSING OF M&V ACTIVITIES

In federal ESPCs, federal agencies are expected to:

- Witness baseline, post-installation, first-year, and annual M&V inspections
- Witness the commissioning of installed ECMs
- Approve required submittals in writing

These inspections will help ensure that all scheduled activities are properly conducted, increase the confidence in the documentation submitted to the federal agency by the ESCO, and ensure that the agency representative is apprised of any ongoing performance issues. Agency participation in the M&V activities does not take the place of a thorough technical review of all submittals.

As detailed in Section 10 of this document, witnessing of key M&V activities by a knowledgeable agency representative is strongly suggested, and should be clearly specified in the project-specific M&V Plan.

7.7 REPORTING

The M&V submittals detailed in the M&V Plan are the Post-Installation Report, the Annual Reports, and any additional periodic reports required. Reporting formats for these reports are defined by the Super ESPC's master contract. Specific content requirements, schedules, and approval procedures for each ESPC project are defined in the project-specific M&V Plan. All of the submittals, however, should adhere to the same general standards and procedures.

7.7.1 Communicating M&V Activities to Federal Agencies

ESCOs must notify the federal agency whenever they are about to install and calibrate metering equipment, remove metering equipment, or perform a site inspection. Enough lead-time must be given in case the federal agency needs to witness the activities or conduct a site inspection before the equipment is either installed or removed. The federal agency can conduct progress inspections of metering, as required.

7.7.2 Format and Content

For Super ESPC projects, the format and content of the key reports are prescribed, and are included in Appendix C of this document.

In general, all relevant documentation should be included with the M&V submittals, and these data should be provided in both electronic and hard-copy formats, as specified by the federal

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32 FEMP's website is http://www1.eere.energy.gov/femp/.

agency. When submitting an M&V report, ESCOs should provide the data supporting the M&V activities. Data formats should be specified in the M&V Plan, and both the original data and final data analyses should be submitted in support of surveys, savings estimates, and calculations. Metered data must be furnished in formats that are usable by the federal agency and based on products or software that are publicly available. For billing analysis and computer simulation M&V methods, electronic and hard-copy input and output files must be provided. If special software products are required for the reading or analysis of ESCO submittals, the federal agency may reject the data or request that the ESCO supply the software.

7.7.3 Approvals

Federal facility personnel ensure that the report and verification documentation are complete and accurate and in compliance with the contract and approved site-specific M&V Plan. The federal agency must approve these submittals in writing. Federal Acquisition Regulation (FAR)[33] provisions require agencies to verify in writing that the terms and conditions of the contract agreement have been met, prior to payment by the government. Verbal communication concerning changes or acceptance of ESCO M&V submittals is not binding on the federal agency. All submittals, changes to submittals, and approvals must be in writing and signed by an authorized party, as indicated in the ESPC Task Order.

If the federal agency believes that the conditions at the site are not accurately represented by the ESCO's submittals, the ESCO will be allowed to address the problem and make a new submittal. If the ESCO and federal agency cannot agree on site conditions, however, a contract or project may be modified or terminated. The federal agency's inspection personnel do not have the authority to approve changes to contract documents or ESCO submittals to the federal agency. The federal agency's authorized representative must approve submittals and any changes.

7.8 ANNUAL INSPECTIONS

For Super ESPC projects, an annual inspection of the energy conservation measures is required by DOE's ESPC regulations.[34] This inspection may be conducted by the federal agency or the ESCO, and is intended to verify that the installed equipment/systems have been properly maintained, continue to operate correctly, and continue to have the potential to generate the predicted savings. Typically, the ESCO will perform an annual site inspection while being accompanied by an agency representative. Any measurements or monitoring required by the M&V Plan may be executed in conjunction with this site visit. The federal agency can witness metering, as required.

Although an Annual Report from the ESCO is required to substantiate savings guarantees and adjust payments, if required, more frequent verification activities can be appropriate. This ensures that the M&V monitoring and reporting systems are working properly; it allows fine-tuning of measures throughout the year based on operational feedback, and it avoids surprises at the end of the year.

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33 Federal Acquisitions Regulation

34 See DOE Final Rule, 10 CFR 436 Subpart B – Methods and Procedures for Energy Savings Performance Contracting, April 10, 1995, Section 436.37.

These periodic inspections by both the ESCO and agency staff will help ensure that all scheduled activities are properly conducted, increase the confidence in the documentation submitted to the federal agency by the ESCO, and ensure that the agency representative is apprised of any ongoing performance issues. Agency participation in the M&V activities does not take the place of a thorough technical review of all submittals, including Annual Reports.

The Annual Reports should include:

- Results/documentation of performance measurements and inspections
- Realized savings for the year (energy, energy costs, O&M costs, other)
- Comparison of actual savings with the guaranteed amounts
- Details of all analysis and savings calculations, including commodity rates used and any baseline adjustments performed
- Summary of O&M activities conducted
- Details of any performance or O&M issues that require attention

Detailed review instructions are provided in Chapter 10 of this document.

7.9 O&M AND OTHER ENERGY-RELATED SAVINGS

O&M and other energy-related cost savings are allowable in federal ESPCs, and are defined as reduction in expenses (other than energy cost savings) related to energy and water consuming equipment. Energy-related cost savings can result from avoided expenditures for operations, maintenance, equipment repair, or equipment replacement due to the ESPC project. This includes capital funds for projects (e.g., equipment replacement) that, because of the ESPC project, will not be necessary. Sources of energy-related savings include:

- Avoided current or planned capital expense
- Transfer of responsibility for O&M and/or equipment repair and replacement (R&R) to the ESCO
- Avoided renovation, renewal, or repair costs as a result of replacing old and unreliable equipment

Specific guidance on documenting and verifying O&M savings in federal ESPCs was developed by a industry-government working group. The resulting document, How To Determine and Verify Operating and Maintenance (O&M) Savings in Federal Energy Savings Performance Contracts, is included as Appendix C.

The general rule to follow is that any savings claimed from O&M activities must result in a real decrease in expenditures. O&M budget baselines cannot be based on what the agency should be spending for proper O&M; baseline expenditures must be based on what the agency is spending. The agency’s O&M expenditures after implementation need to decrease for savings to be considered real. “Savings” due to redirected labor or O&M efforts that do not reduce real expenditures cannot be claimed as savings under the Super ESPC program. For example, labor reductions for agency staff may not qualify as “real savings” if labor expenditures do not decrease.

The approach for calculating energy-related cost savings mirrors the concepts used for determining energy savings—performance-period labor and equipment costs are subtracted from baseline values, plus or minus any adjustments required. Similarly, determining the appropriate level of effort to invest in the M&V of energy-related cost saving is the same as for energy cost savings—the level of M&V rigor will vary according to 1) the value of the project and its expected benefits, and (b) the risk in not achieving the benefits. A graded approach towards measuring and verifying O&M and R&R savings is advised.

Baseline O&M and R&R costs should be based on actual budgets and expenditures to the greatest extent practical. This essentially "measures" the baseline consumption of these parts or services. The use of estimated expenditures should be avoided if at all possible. Performance period or baseline adjustments are used to reflect any site-specific factors that would affect costs.

Some additional key points to keep in mind are as follows.

- An agency's decision to commit ongoing funds from O&M budgets towards ESPC project payments has a long-term impact and must be documented adequately for future agency staff in both the M&V plan and the annual reports.
- Agencies should maintain O&M cost records that will be needed to document baseline O&M costs. These records should be included in the Super ESPC proposal.
- ESCOs should include detailed information in annual reports to clearly convey the source of O&M savings as well as sufficient data to verify any savings calculations performed.
- Escrow accounts can help alleviate R&R risk for both the ESCO and agency.
- Using an Option B or continuous measurement approach to tracking ongoing O&M savings can be cumbersome to the agency because of the required record keeping and accounting for ongoing changes at the site.

More specific guidance on how to determine and verify energy related savings, including examples, is included in Appendix C.

8.1 OVERVIEW

Commissioning of installed equipment and systems is considered industry best-practice and is required on projects implemented under DOE's Super Energy Savings Performance Contract (Super ESPC) . Commissioning ensures that systems are designed, installed, functionally tested in all modes of operation, and are capable of being operated and maintained in conformity with the design intent (i.e., appropriate lighting levels, cooling capacity, comfortable temperatures, etc.). Benefits of commissioning include increased building comfort, reduced operational problems, lower installation costs, fewer contractor call-backs, and improved energy performance. The commissioning requirements outlined herein have been adapted from industry standard procedures detailed in ASHRAE's commissioning guidelines.[35]

Commissioning (Cx) is a process that begins at project conception and typically ends after project acceptance. Key activities in the commissioning process include documentation of design intent, design reviews, execution of construction checklists, systematic functional testing of equipment and systems, oversight of training for operations and maintenance staff, and follow-up on any warranty issues.

Commissioning usually requires taking performance measurements to ensure that systems are working properly. Because of the overlap in commissioning and post-installation measurement and verification (M&V) activities, some people may confuse the two. The difference is that commissioning ensures that systems are functioning properly; post-installation M&V quantifies how well the systems are working from an energy standpoint.

Following the commissioning process will help realize the full potential of the energy conservation measures (ECMs), but key issues must be anticipated and planned. These issues are discussed in this section, and include:

- Allocating adequate resources and time to the commissioning process
- Appointing a commissioning agent (CxA), and/or prescribing the affiliation and qualifications required
- Providing an overview of roles and responsibilities for CxA, agency, and ESCO
- Making provisions to document the design intent for each system or ECM
- Incorporating a process for design reviews and submittal approvals
- Specify commissioning reporting requirements.

8.2 COMMISSIONING PROCESS FOR ESPCS

Because of the design-build nature of ESPCs, the details of the commissioning activities are developed along with the project scope, rather than being explicitly defined at the beginning of the project. In an ESPC, the commissioning activities are:

[35] ASHRAE Guideline 1-1996 The HVAC Commissioning Process and ASHRAE Guideline 0-2005 The Commissioning Process

- Specified in the contract
- Defined explicitly after design
- Implemented during construction
- Completed prior to final project acceptance
- Reviewed after project acceptance.

The sections below outline the key commissioning activities and considerations in an ESPC. The complete commissioning process is described in ASHRAE Guideline 0[36].

8.2.1 Specifying Commissioning Requirements in the Contract

The scope of work for an ESPC project usually evolves from an investment grade energy audit, which includes descriptions of energy conservation measures (ECMs), analyses of energy and cost impacts, and the basis for a savings or performance guarantee. The contract negotiations and scope are completed based on the conceptual design presented in the energy audit. For complex projects, the design is typically about 30% complete at the time of contract award. Since the detailed design of the project often occurs after the contract is in place, it is impractical to define all details of the project's commissioning in the contract. It is critical, however, to include sufficient details on the commissioning process that will be followed for the duration of the project to ensure the benefits of commissioning are realized.

The contract should outline the project's specific commissioning requirements. The key items that should be specified include:

- The affiliation and qualifications of the Commissioning Agent (CxA)
- Roles and responsibilities of CxA, ESCO and agency, including witnessing of Cx activities
- Process that will be followed to document the design intent or agency's project requirements for each energy conservation measure (ECM) or system
- Requirements for agency or third-party design reviews or submittal approvals
- Schedule for developing and approving a Cx plan, including expected content such as:
  - Pre-functional inspections
  - Functional testing procedures
  - Required use of manufacturer start-up procedures
  - Plan for seasonal testing and conditional acceptance, if needed
- Contents and timing of the Final Cx Report, Systems Manual, and any periodic project reports
- Requirements for CxA oversight of O&M training

[36] ASHRAE Guideline 0-2005 The Commissioning Process

- Plan for warranty walk-though or other follow-up procedures

The contract should designate both the affiliation and qualifications of the CxA that will lead the commissioning process for the project. The key responsibilities of the CxA are: 1) directing the commissioning team in the completion of the commissioning requirements; 2) overseeing or performing the commissioning tests; and 3) verifying the adequacy of the commissioning results.

In the ideal scenario, the CxA will be from an independent third party reporting directly to the agency. In some cases the CxA may be a qualified member of the agency's staff, but sufficient time and resources must be allocated for fulfillment of this role. Typically, it is a challenge to simply identify an in-house project manger, much less a CxA.

Often in ESPCs, the CxA may be from the energy service companies (ESCO). In this situation, the CxA should *not* be part of the design or construction management team, but another individual that meets the prescribed qualifications. In many cases, however, utilizing project funds to engage a third party CxA, rather than have the ESCO utilize internal resources, is advisable. While it is essential that contractors verify and test the installed systems, formal commissioning requires independent oversight which ensures that the agency's best interests are maintained.

Key qualifications for the individual acting as CxA include onsite availability, experience executing the Cx process, hands-on experience in testing and troubleshooting applicable systems, familiarity with a variety of testing equipment, and detailed understanding of the systems and equipment affected by the project.

In addition to identifying the affiliation and qualifications for the CxA, the agency should specify a representative to witness the Cx activities and to resolve any disputes that might arise. The agency's Cx representative will also be expected to provide some oversight and approval of the commissioning activities.

If not already included, the contract should mandate the development of a written design intent for each system or ECM installed that documents the agency's project requirements. Specific operational parameters, design details, performance requirements (conditions in addition to energy savings), or other provisions that are established by a design intent are:

- Operational parameters, such as temperature setback capabilities or operator interface features
- Requirements for design details or ancillary items, such as sensors, valves, access, electrical, existing equipment demolition, etc.
- Performance requirements, such as equipment efficiencies, or ton-hours of chilled water to be delivered

8.2.2 Defining Commissioning Activities During Project Design

Once the ESPC contract has been awarded, any remaining design and engineering of the project scope is completed. Commissioning related activities performed by the Cx team in the design phase include:

- The ESCO completes the project design
- The agency and CxA review design and approve equipment submittals
- The ESCO and agency document the design intent for each ECM or system
- The CxA develops a draft Cx Plan, including the specifics of all pre-functional inspections and functional performance tests
- The CxA develops Cx specifications for the project (if needed)
- The agency and ESCO review and accept Cx documents
- The CxA issues Final Commissioning Plan and specifications

8.2.3 Implementing Commissioning Activities During Construction

After the design and commissioning plan have been finalized, construction begins. Cx-related activities that occur during the construction phase include:

- Construction is observed by the agency's Cx representative and the CxA
- Periodic Cx meetings are held with the project team;
- Cx progress reports are submitted by the CxA
- Pre-functional inspections are completed and certified by the ESCO prior to equipment start-up and functional testing
- Manufacturer start-up procedures are completed by the ESCO or manufacturer's representative

8.2.4 Completing Commissioning Activities Prior to Project Acceptance

Once construction has been completed and ready for acceptance by the agency, the functional performance tests are executed and the procedures are documented by the CxA. The CxA documents the test results, explicitly including how the agency's project requirements or design intent prescribed for each system were met. Any items that did not pass are tracked and presented to the project team in a deficiency log. The ESCO then rectifies the items and performs a retest in the presence of the CxA to confirm that the items have been fixed. The deficiency log is then updated by the CxA, noting the date and corrective action taken. The agency may choose to specify consequences for multiple failed retests to limit the possibility of excessive use of the CxA's time.

It is common for the CxA to oversee and ensure the adequacy of the O&M training in order to ensure that the ECMs and systems are properly maintained and operated. Some ECMs, such as natural ventilation, daylighting, night time flushing, and use of building thermal mass, result in a building that behaves differently than a conventional building. It is important that the commissioning contractor, building maintenance staff, and occupants understand how the building works. For example, an energy management behavioral program for employees is one way to educate building occupants.

Depending on the preference of the agency, the ESCO then assembles the Final Commissioning Report or a Systems Manual, as prescribed in the contract. At a minimum, a Final Cx Report should be provided, which typically includes:

- Commissioning summary report
- ESCO-certified pre-functional checklists
- Completed manufacturers startup sheets
- Results of functional testing and verification of system performance
- Detailed operating procedures/sequences of operations
- Closed-out deficiency log
- Overview of training provided to O&M staff.

Some agencies may prefer to receive a more comprehensive Systems Manual, which is required for LEED[37] certification. A Systems Manual typically brings together comprehensive project documentation, including:

- Agency's project requirements or design intent
- Schematic system drawings
- Approved submittals
- Recommended record keeping procedures
- Maintenance procedures and schedules
- Test requirements for ongoing commissioning

8.2.5 Post-Acceptance Phase Commissioning Activities

Commissioning activities that typically extend beyond Project Acceptance include deferred functional testing and warranty verification.

Often, some functional testing may be postponed until seasonal conditions are appropriate to evaluate the system. When some functional testing has been deferred, acceptance of the project is conditional upon the success of the scheduled tests.

Most equipment installed will have a 1-year warranty provided by the manufacturer. A warranty check-out with the ESCO after 8 to 10 months of operation is a recommended commissioning activity. Reviewing the equipment warranties and performing a site walk-though at this time can identify any problems that may still be covered by a manufacturer's or contractor's warranty.

[37] Leadership in Energy & Environmental Design is a Green Building Rating System, developed by the U.S. Green Building Council.

Section 9 Planning and Reporting for Operations & Maintenance

In performance contracts, operation and maintenance (O&M) is critical to maintain the performance of the installed equipment, to achieve the guaranteed energy savings, and to minimize the chance of unexpected repair and replacement issues arising for the term of the contract.

This chapter provides guidance on:

- Allocating O&M and repair and replacement (R&R) responsibilities; and
- Incorporating O&M reporting requirements.

9.1 OVERVIEW

Either the ESCO or the government (or the government's representative) may perform O&M activities on equipment installed as part of an ESPC. However, the ESCO is ultimately responsible for ensuring the performance of new equipment installed as part of the ESPC throughout the duration of the ESPC contract term. The government is typically responsible for existing equipment.

In an ideal scenario, the ESCO will both operate and perform all maintenance activities on equipment installed in an ESPC project. In many cases, however, it is not practical for the ESCO to carry out these activities. Often, the site is accustomed to performing O&M and the cost of reallocating these responsibilities is not be feasible within the ESPC contract term, since services must be paid from savings. In other instances, limited site access or other issues may make government O&M preferable.

A critical factor in the success of an ESPC is to ensure that the O&M plan for new equipment relates well to the O&M approach for existing equipment. This is especially true when new and existing equipment are located in the same facility or when existing equipment has a potential effect on the operation or savings achieved by new equipment. Clear definition of roles and responsibilities for O&M contribute toward proper coordination of O&M activities for new and existing equipment

9.2 STEPS TO PLAN & REPORT ON O&M AND R&R ISSUES

The activities required for ensuring proper planning and reporting for O&M and R&R are summarized in the Table 9-1, and discussed in this section.

Table 9-1 Steps to Plan & Report on O&M and R&R Issues

Step 1:	Develop ESPC contract Risk & Responsibility Matrix to allocate overall responsibilities.
Step 2:	Develop detailed O&M responsibilities and reporting requirements in the contract.
Step 3:	Develop project-specific O&M checklists.
Step 4:	ESCO assembles O&M manuals & provides training to site staff.
Step 5:	Government (or ESCO) periodically reports on maintenance procedures performed.
Step 6:	ESCO submits Annual Report on project performance.

9.2.1 Step 1: Develop ESPC Contract Risk & Responsibility Matrix

Early in the Super ESPC project development phase, the agency and the ESCO allocate overall project responsibilities by completing the Risk & Responsibility Matrix. Key items related to O&M and R&R are included in the Performance section of the Risk & Responsibility Matrix, and cover four topics: Equipment Performance, Operations, Maintenance, and Equipment Repair & Replacement. These sections are detailed in the table below.

The ESCO is responsible for the guaranteed savings of the contract and thus ultimately responsible for all O&M related items. The responsibility for hands-on performance these items may be accomplished by the ESCO or the Government, or shared, as agreed upon for the specific project. Financial, security, or other factors may cause the government to decide to accept responsibility for conducting the O&M activities.

Table 9-2 Excerpt from Risk & Responsibility Matrix[38]

3. Performance:
a. Equipment performance: The contractor has control over the selection of equipment and is responsible for its proper installation, commissioning, and performance. The contractor has responsibility to demonstrate that the new improvements meet expected performance levels including specified equipment capacity, standards of service, and efficiency. Clarify who is responsible for initial and long-term performance, how it will be verified, and what will be done if performance does not meet expectations.
b. Operations: Performance of the day-to-day operations activities is negotiable and can impact performance. However, the contractor bears the ultimate risk regardless of which party performs the activity. Clarify which party will perform equipment operations, the implications of equipment control, how changes in operating procedures will be handled, and how proper operations will be assured.
c. Preventive Maintenance: Performance of day-to-day maintenance activities is negotiable and can impact performance. However, the contractor bears the ultimate risk regardless of which party performs the activity. Clarify how long-term preventive maintenance will be assured, especially if the party responsible for long-term performance is not responsible for maintenance (e.g., contractor provides maintenance checklist and reporting frequency). Clarify who is responsible for performing long-term preventive maintenance to maintain operational performance throughout the contract term. Clarify what will be done if inadequate preventive maintenance impacts performance.
d. Equipment Repair and Replacement: Performance of day-to-day repair and replacement of contractor-installed equipment is negotiable, however it is often tied to project performance. The contractor bears the ultimate risk regardless of which party performs the activity. Clarify who is responsible for performing replacement of failed components or equipment replacement throughout the term of the contract. Specifically address potential impacts on performance due to equipment failure. Specify expected equipment life and warranties for all installed equipment. Discuss replacement responsibility when equipment life is shorter than the term of the contract.

9.2.2 Step 2: Develop Detailed O&M Responsibilities and Reporting Requirements

Once the ESCO and Government agree-upon O&M related responsibilities in the Risk & Responsibility Matrix, the detailed requirements supporting these responsibilities must be included in the contract. For Super ESPC projects, the allocation of O&M responsibilities is discussed in the Site Management Plan, and O&M reporting requirements are defined in the

[38] See complete ESPC Risk, Responsibility and Performance Matrix in Section 3.

M&V Plan. Ensuring that all related items are appropriately defined requires careful contract development and review.

When the government elects to perform O&M activities on new equipment, several issues will require careful review because the ESCO may be compensated by the government to take over the O&M activities if inadequate O&M threatens the realization of savings, equipment reliability or equipment life. These issues include:

- Provisions for ESCO to monitor Government performance of O&M
- Specific O&M record keeping / reporting requirements by government
- Procedures for ESCO review / verification of O&M records
- Impact of O&M of old equipment on new equipment
- Define criteria for ESCO to take over operations
- Define criteria for ESCO to take over maintenance (Prior to equipment failure)
- How does ESCO get paid for performing Government's activities?

Table 9-3 Excerpt from M&V Plan & Savings Calculations Outline

From Whole Project Data / Global Assumptions
2.4 Operations, Preventive Maintenance, Repair, and Replacement Reporting Requirements
2.4.1 Define Government and ESCO reporting requirements:
Summarize key verification activities and reporting responsibilities of government and ESCO on operations, preventive maintenance, repair, and replacement items from details in ECM specific M&V Plans.
Define content of reports and reporting schedule.
From ECM Specific M&V Plan (for each ECM)
3.7.8 Define operations, preventive maintenance, repair, and replacement reporting requirements.
Detail verification activities and reporting responsibilities of government and ESCO on operations, preventive maintenance, repair, and replacement items.
Define contents of report and reporting schedule, if different than in global section 2.4.

9.2.3 Step 3: Develop Project-specific O&M Checklists

For projects in which the government accepts some responsibility for O&M activities, the ESCO must define the required activities. Although checklists are not always required in the contract, it is a good idea to develop one for those ECMs that may have extensive preventive maintenance requirements and/or where O&M responsibilities may be distributed. Typically, the ESCO will develop the O&M checklists listing specific O&M tasks, their frequency, and the party responsible for carrying out those activities.

For O&M checklists to be effective, both the ESCOs and the agency must agree on them and be committed to performing the O&M tasks on time. For this reason, it is recommended that the O&M checklists should be submitted as part of the Final Proposal. If including finalized checklists is not reasonable, preliminary checklists indicative of the final scope of work should be included.

Checklists not only provide a good way for ensuring that routine O&M activities are being performed on time but it also provides an effective method of documenting and tracking distributed responsibilities. Developing comprehensive O&M checklists that are consistent with the O&M manual is an excellent way to maximize the performance of installed equipment and ensure savings persistence over the term of the ESPC contract.

FEMP's O&M Best Practices Guide[39] has standard O&M checklists for chillers, lighting, fans, pumps, electric motors, air compressors, cooling towers, steam traps, and building control systems.

9.2.4 Step 4: ESCO Assembles O&M manuals & Provides Training

As detailed in the contract, the ESCO will prepare the O&M manuals and provide related training to the site staff. Often, the O&M manuals will become the basis for proper O&M of installed equipment and should include any project specific O&M checklists that will be used. Further, the responsibilities of the two parties detailed in the O&M manuals should be consistent with the contract. Once the O&M manual is submitted by the ESCO, it is the government's responsibility to check that the O&M manuals meet the requirements specified in the contract and are adequate for government records.

Generally, O&M manuals (ASHRAE 1993,[40] 1996[41]) should include a master list of installed equipment, including all information pertinent to proper operations and maintenance. Information on each piece of major equipment typically includes:

- **Names and contact information** for the equipment reps, vendors or manufacturers;
- **Model and size and its location** in the campus/building;
- **Operating instructions including** start-up, shut down, emergency conditions, safety precautions, and trouble shooting suggestions;
- **List procedures** that must be followed while operating equipment;
- **Preventive maintenance instructions** including maintenance, overhaul, and lubrication instructions;
- **Checklist** that will be used as the basis to perform the O&M procedures. Preventive maintenance actions shall preferably be categorized by recommended frequencies.

9.2.5 Step 5: Government (or ESCO) Periodically Reports on Maintenance Performed

Since the ESCO is responsible for the performance of new equipment for the term of the contract, it is often appropriate for the government to document the completion of any O&M procedures performed. The O&M checklists developed in Step 3 should be utilized to record these activities.

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39 Operations and Maintenance (O&M) Best Practices Guide - A Guide To Achieving Operational Efficiency V 2.0 is available at http://www1.eere.energy.gov/femp/operations_maintenance/om_bpguide.html

40 ASHRAE Guideline 4: Preparation of Operating and Maintenance Documentation for Building Systems. Atlanta, GA: ASHRAE, 1993.

41 ASHRAE Guideline 1: The HVAC Commissioning Process. Atlanta, GA: ASHRAE, 1996.

Although the ESCO is required to submit annual reports that include a summary of O&M activities, described below, there are instances when additional reporting on O&M may be required. These reporting requirements were identified in the Final Proposal and should be included in the contracted M&V plan.

9.2.6 Step 6: ESCO Submits Annual Report

A minimum of annual performance reporting is required for Super ESPC projects. The Annual Report Outline provides sufficient O&M reporting provisions for most ECMs. These requirements should be reviewed during contract development. The portions related to O&M in Annual Report Outline are detailed in Table 5.

This step will only provide value if appropriate actions are taken to address issues that are identified during the performance period. Following-up on problems identified in the Annual Report is an important key to savings persistence.

Table 9-4 Excerpts from Annual Report Outline for Each ECM

1. Executive Summary
1.5 Performance and O&M Issues • Note impact of operating deficiencies or enhancements on generation of savings • Note impact of maintenance deficiencies on generation of savings • Detail any deficiencies needed to be addressed by ESCO or Government
2. Details for ECM
2.5 O&M and Other Activities 2.5.1 Operating requirements: • State organization(s) responsible for equipment operations. If appropriate, detail how responsibilities are shared. • Summarize key operating procedures and any related verification activities. • Detail any deficiencies needed to be addressed by ESCO or Government • Note impact of operating deficiencies or enhancements on generation of savings
2.5.2 Preventive maintenance requirements: • State organization(s) responsible for performing maintenance. If appropriate, detail how responsibilities are shared. • Verification of scheduled maintenance items completed by ESCO or Government • Detail any deficiencies needed to be addressed by ESCO or Government • Note impact of maintenance deficiencies on generation of savings
2.5.3 Repair & replacement requirements: • State organization(s) responsible for repair and replacement. If appropriate, detail how responsibilities are shared. • Summary of activities conducted this period by ESCO or Government • Detail any deficiencies needed to be addressed by ESCO or Government • Note impact of equipment deficiencies on generation of savings

The purpose of agency oversight and review of M&V activities is to:

- Verify that all M&V activities are conducted in accordance with the M&V plan;
- Confirm that the reported results of inspections and measurements are accurate and represent actual operation of the equipment or systems involved;
- Confirm contractor payments are based on verified savings;
- Ensure that M&V activities are properly documented; and
- Follow-up on any outstanding issues identified.

Government agencies are expected to witness baseline, post-installation, first-year, and annual measurement and verification (M&V) inspections and commissioning of installed ECMs, and approve required submittals in writing. This requires that the agencies designate individual(s) to observe these inspections, review the resulting M&V reports by the ESCO, and certify in writing that those reports are acceptable to the agency. Detailed requirements for each project will be included in the project specific M&V Plan.

Depending on available resources, the agency may seek outside assistance in the review of M&V reports, analyses, and results. The government representative who is responsible for oversight of M&V activities and review and acceptance of reported findings should have significant experience in the analysis, design, commissioning or measurement and verification of energy efficiency projects, and be familiar with both the site and the details of the ESPC project. Recommended qualifications for the representatives conducting these activities are provided in *Guide to Government Witnessing and Review of Post-Installation and Annual M&V.*[42]

10.1 GOVERNMENT WITNESSING OF M&V ACTIVITIES

Witnessing of M&V activities by knowledgeable agency representative(s) is recommended primarily to:

- Assure that both agency and ESCO fully understand the measurement and verification of savings that justifies payments being made to the ESCO,
- Provide increased confidence that savings expected under the ESPC are being achieved, and
- Make a direct link between payments made to the ESCO and the verification that savings are being achieved.

Active involvement by agency personnel in the verification of savings is recommended by federal oversight agencies, and is required to meet the legislative requirements, including the Federal Acquisition Regulations (FAR). FAR provisions generally require agencies to verify in

[42] Guide to Government Witnessing and Review of Post-Installation and Annual M&V, September 7, 2006 by Agency Witnessing Working Group of the Federal ESPC Steering Committee.

writing that applicable procurement terms and conditions have been met by a contractor, prior to payment by the government.

Active participation in the M&V process by agency staff can reduce the number and intensity of disputes about performance, as well as fulfill the legislative requirements. Additional guidance on these issues is presented in *Guide to Government Witnessing and Review of Post-Installation and Annual M&V*.[43]

10.2 USING THE REVIEW CHECKLISTS AND REPORT TEMPLATES

Review checklists and templates for written reviews of M&V Plans, Post-Installation Reports, and Annual Reports are included in Appendix D. These checklists and templates should be utilized to complete a thorough evaluation by an agency representative prior to accepting the submitted M&V plan, Post-Installation Report, or Annual Report.

10.2.1 Project Documentation Needed

Prior to conducting the review, ensure that all related project documentation is on-hand. At a minimum for any ESPC project report or M&V plan review, the M&V plan, the final cost schedules, and any contract modifications should be available. For review of Annual Reports, the Post-Installation Report and any previous Annual Reports are needed. Savings calculations should be carefully scrutinized, and will often need to be reviewed in their electronic format. Missing documentation can cause confusion and lead to incorrect conclusions.

10.2.2 Using the Checklists

The layout of the checklists follows the prescribed outlines for M&V Plans, Post-Installation and Annual Reports (Appendix C) and each one has two parts - Project Level items and ECM Level items. Prior to beginning the review, determine the percent contribution of cost savings for each ECM in the project (from cost schedule TO-4 Task Order Performance Period First Year Estimated Annual Cost Savings by ECM), and prioritize the measures that will save the most. The reviewer should customize the review checklists found in Appendix D and available electronically[44].

Principal review efforts should be focused on the measures providing the largest portion of the cost savings for the project. This strategy of reviewing the principal cost saving measures first will help the reviewer spend the smallest amount of time while maximizing the value of the review, and is especially helpful when review time is limited. Provide a detailed review of the M&V strategy for each measure if possible.

Read through the M&V submittal (Plan, Post-install, or Annual Report) while checking off topics and making notes in the customized checklists. Note the location of key items in the first column of the checklists (labeled “Reference Page”) so they can be easily cross-referenced. The inability to comment on an item suggests that relevant information may be missing or not in complete form. Items in the checklist that require follow-up should be flagged by placing an

[43] Guide to Government Witnessing and Review of Post-Installation and Annual M&V, September 7, 2006 by Agency Witnessing Working Group of the Federal ESPC Steering Committee.

[44] Electronic versions of the review checklists are available at http://www1.eere.energy.gov/femp/financing/superespcs_mvresources.html

"X" in the last column of the checklist (labeled "Follow-Up?") and noting the deficiency or issue identified in the adjacent column. Some of the items in the checklists are marked "Evaluation". This indicates that additional qualitative assessment is necessary. These qualitative issues are discussed for each individual M&V submittal type in subsequent sections of this chapter.

10.2.3 Summarize Findings in Evaluation Report

After reading the M&V submittal (Plan, Post-Installation or Annual Report), filling out the Review Checklists, and evaluating the qualitative issues, the findings from the review should be summarized in a written report. The written review should follow the format in the appropriate Review Template and include the completed Review Checklists. The format of the report can be modified as needed to meet the specific project needs. Complete all the sections and customize placeholder text included in the Review Template, and delete any instructions once completed.

The written review of the M&V submittal should be provided to the agency staff, as well the DOE representative, who will archive it for project records. The agency should follow up on any questions or action-items identified through the review, including the ESCO as appropriate, and document any subsequent actions taken.

10.3 REVIEWING M&V PLANS

Evaluating M&V plans is an inexact science that requires technical expertise and experience. Ideally, the reviewer will have been involved in the project development phase and has an intimate understanding of the agency's goals, the agree-upon allocation of project risks, site specific issues, as well as the objectives and constraints for each ECM.

The M&V Plan deserves careful evaluation as it defines the requirements for all future M&V activities. Discussion with the agency on the findings from the M&V plan review is usually warranted, and may result in revisions to the M&V plan. Often, the review process is iterative. After an initial review, subsequent revisions of the M&V plan must be assessed to determine if adequate modifications have been made. Written evaluations of these subsequent M&V plans are needed to document follow-up actions taken.

10.3.1 Prescriptive and Qualitative Evaluation Items

The first step in evaluating an M&V plan is to complete the M&V Plan Review Checklists. The inclusion of all items on the checklists does not indicate the appropriateness of the M&V approach, only that the required information is included. Each measure requires extensive qualitative assessment, and tips for evaluating the M&V approach are included therein. All findings resulting from review, including completed checklists, should be included in the evaluation report, as discussed in Section 10.2.3.

Evaluate overall project level items:

- Do all M&V strategies included in Plan support the concepts included in Risk & Responsibility Matrix?
- Are contracted energy rates based on actual rates, including time-of-use rates and peak demand ratchets? Are marginal (not blended) energy rates used?
- Are proposed escalation rates based on latest NIST data (see Section 7.5.1)?

- Are M&V costs reasonable? Do costs align with planned activities?
  - See TO-2 for Initial M&V cost for each measure. See TO-4 for performance period M&V costs
- Are ancillary payments required to make the project cash-flow?
- Is the level of savings predicted reasonable? Were project level savings compared to overall site usage? (optional)
- Were all objectives and constraints of the project considered?

Assess each ECM:

- Review agreed-upon Responsibility Matrix for the project. Ensure the M&V strategy for each measure conforms to the agreed-upon risk allocation.
- Note the source(s) of cost savings for each measure (O&M, electricity, demand, natural gas, water, etc.). Ensure M&V activities are adequate for all significant sources of savings.
- What is the likelihood for success for this measure? More rigorous M&V strategies are warranted for ECMs with substantial uncertainty and/or technical complexity.
- Is the level of savings predicted reasonable? Were ECM savings compared to system usage?
- Were key variables affecting energy use measured for each ECM (e.g. watts/fixture and hours/yr)?
- Do the measurements include the parameters that are the source of the savings (e.g. reduction in watts/fixture or hours/yr)?
- Are M&V costs reasonable? Do costs align with planned activities?
- See TO-2 for Initial M&V cost for each measure. See TO-4 for performance period M&V costs.

Consider the adequacy of baseline developed:

- Are all assumptions / stipulations reasonable, and includes source of data?
- Were system performance characteristics recorded (e.g. lighting intensities, temperature set points)?
- Where energy calculations closely reviewed?
- Are savings estimates sound & reasonable?
- Were utility or weather based models validated?

Evaluate the quality of performance period activities:

- Is meaningful ongoing performance period data going to be used to calculate savings?
- What is being verified? Is this sufficient to support the guarantee?
- Will key variables affecting energy use be measured for this ECM? How often?

- Will single post-installation measurements apply to all years in the performance period? If so, how valuable are the data used?
- How likely is this data to change over the performance period?
- Based on which party has accepted ongoing responsibility for each item, is this approach appropriate?

Review the strategy for conducting O&M for this ECM:

- Are O&M activities sufficiently detailed to demonstrate level of effort?
- Are responsibilities allocated as suggested by R&R Matrix?
- Are reporting requirements adequately defined?

10.4 REVIEWING POST-INSTALLATION AND ANNUAL REPORTS

Evaluating the Post-Installation and Annual Reports is more straight forward than reviewing M&V plans, as the level of qualitative assessment and engineering judgment required is considerably less. These reports document the results of the activities defined in the M&V plan

The *Post-Installation Report* documents the results of verification activities conducted by the ESCO after project installation but prior to project acceptance. This report documents any changes in the project scope and energy savings that may have occurred since the *Final Proposal*, and reports the expected Year 1 energy and cost savings. Keep in mind that many applications of M&V Option A methods, measurements are only taken once following installation. Subsequent activities may be limited to inspections to verify ‘potential to perform.’ The Post-Installation Report is therefore a critical document for projects using an Option A approach.

Similarly, each year during the performance period the contractor submits an *Annual Report* which documents the execution and results of the periodic M&V activities prescribed in the M&V plan (i.e. measurements, inspections, savings calculations, O&M activities), as well as any items that may require additional follow-up. The Annual Report is the basis for determining if the annual savings guarantee has been met, and for determining if any “true-up” of payments is required.

M&V for Super ESPC projects needs to show that the overall savings guarantee has been met, and does not necessarily need to determine the actual savings for each ECM. The total level of cost savings for the project must meet or exceed the guaranteed cost savings for that performance year. If the contractor fails to meet the guaranteed annual savings as verified by the M&V documents, the agency shall adjust the payment schedule, as necessary, to recover the agency’s overpayments in the previous year and to reflect the lower performance level into the current year.

10.4.1 Prescriptive and Qualitative Evaluation Items

The first step in evaluating an M&V report is to complete the appropriate Review Checklists, as discussed in Section 10.2. The inclusion of all items on the checklists indicates the prescribed information is included. A through evaluation of each measure, however, also requires some qualitative and engineering judgment as well, as discussed below. All findings resulting from review, including completed checklists, should be included in the evaluation report, as discussed in Section 10.2.3.

Answer the following key questions:

- Were all activities required by the M&V Plan followed?
- Was the content of the submitted report complete?
- Were the guaranteed savings for the project met? If the guarantee is not fulfilled for the performance year, is the explanation adequate?

Understand any changes in the project's performance:

- Have any ECMs whose savings levels increased or decreased significantly from year to year? Is explanation of why changes occurred in savings values sufficient? If not, why not and what corrective actions will or should be taken? By whom?
  - Note any changes in scope or performance, or results that differ from the Post-Installation or previous year's report
  - Note that ECMs using Option A methods may not show a change even if there are performance problems.
- Did the report provide useful feedback on the performance of each measure?
- Did the report verify the potential of the ECMs to save in future?
- Are there any performance problems, O&M issues, or deficiencies that need to be addressed? By whom?

Review the savings calculations:

- Were calculations submitted in electronic format?
- Was the prescribed savings calculation methodology used? Did the reviewer verify the math in the savings calculations?
- Were rates shown in the final proposal used, and were rate adjustment factors applied correctly?
- If savings result from rate changes, have the baseline and new rates been reported?
- Is the basis for any adjustment valid, and have the adjustments been consistently and uniformly applied?

This section provides a guide for the application of M&V methods to a variety of common energy conservation measures, including:

1. Lighting Efficiency
2. Lighting Controls
3. Constant Speed Motors
4. Variable Speed Motors
5. Chillers
6. Water
7. Geothermal Heat Pumps
8. Renewable Technologies
9. New Construction

11.1 LIGHTING EFFICIENCY

One of the most common energy conservation measures implemented in ESPCs is lighting efficiency improvements due to equipment retrofits or replacements. The source of savings in lighting efficiency projects is reduced lighting demand and energy use due to higher efficiency lighting equipment.

Key considerations related to M&V of lighting efficiency projects include:

- Ascertaining existing equipment inventory
- Determining operating hours and a peak diversity factor
- Establishing baseline equipment performance
- Determining performance of new equipment
- Accounting for interactive effects.

Energy savings from lighting retrofits can be accurately predicted using short-term measurements. For this reason, energy savings are often determined and verified using an Option A approach. The recommended approach for federal projects is described below and is demonstrated in the Standard M&V Plan for Lighting Retrofits included in Appendix J.

11.1.1 Equipment Inventory

Equipment inventories, typically on a per-room basis, should include counts of each fixture, lamp, and ballast combination. Additional details that should be included are counts of non-operating fixtures, usage area description, control type (including dual switching arrangements), existing lighting levels, and if space-is heated and/or air conditioned. If a significant number of lamps or fixtures are not operating, the baseline energy use may need to be adjusted to account for burned-out fixtures that are intended for repair. Fixtures that have been purposely de-lamped should be accounted for in their own equipment category.

11.1.2 Operating Hours and Diversity Factor

In lighting efficiency projects without control modifications, baseline and performance period operating hours are assumed to be the same since they are unaffected by the retrofit. The operating hours are a critical component in calculating the savings and need to be accurately estimated. The recommended approach is to measure the operating hours of a sample of fixtures and subsequently stipulate the operating hours based on the monitoring in the contract. Comparing measured operating hours to occupancy schedules provided by the agency can be useful to identify any schedule adjustments that short-term measurements may miss.

When measuring operating hours, it is appropriate to use statistically valid samples and to verify the statistical characteristics of the sample, as discussed in Section 7.4.4 and in Appendix B.

For measurement of operating hours, the fixture inventory is divided into usage groups based on similar operating conditions. Random samples of fixtures are selected from each usage group, the size of which is based on a prescribed confidence and precision (80% and 20%, respectively, are often used). Portable on-off data loggers are then installed in the selected fixtures to measure on/off times, and/or the demand from dedicated lighting circuits is measured using short term monitoring. Current, along with spot-measured power factor and voltage may be (and is often) used as a proxy for power. Measurements are typically conducted for 3 weeks during regular non-holiday operations. The measured operating hours are analyzed to determine the operating profile, which is extrapolated to a full year. Multiple metering periods may be warranted if significant operational variations exist.

For projects that claim peak demand savings, a diversity factor must be determined and applied to baseline and performance period demand to avoid over-counting demand reductions. At any facility, only a portion of the lighting will be on when the building's peak demand charges are set. Sometimes, measured time-stamped operating data collected to determine run hours are used to determine the percent of lights in operation during the peak period, and on other occasions the diversity factor is estimated. The diversity factor can be an overall weighted factor of all lighting included in the project, or it can be determined for each usage group. Agencies should be wary of any approach that blends peak demand (kW) savings with consumption (kWh) savings. Demand savings should be reported independently and the cost impacts calculated separately from energy savings.

11.1.3 Equipment Performance

As discussed in Section 4.2, when applying an Option A approach, the key parameter must be measured. For lighting efficiency projects, the key parameter is fixture power. For lighting projects to be compliant with IPMVP, both the power of baseline and performance period fixtures should be measured.

Another performance metric that should be documented is the baseline and performance period lighting levels. In most cases, light levels are not expected to change significantly as a result of the retrofit. Any change in light levels from the baseline condition should be specified by the agency. Representative pre- and post-retrofit light levels should be recorded. Specific procedures need to be specified in conducting lighting level measurements, an example of which is included in the Standard M&V Plan for Lighting Retrofits shown in Appendix J.

In best practice applications, both the baseline and performance period demand on the various fixture types should be measured. Sampling strategies outlined for operating hours (above) should be separately applied to fixture powers in both the baseline as performance period cases. When measuring fixture power, one should use either 1) true root-mean-squared (RMS) measurements, or 2) current as a proxy for power when combined with spot-measured volts and power factor. Meters with accuracy at or approaching ±2% of readings should be employed. Using lighting circuit measurements requires dedicated lighting circuits with known loads. Non lighting loads should not be included in the measured circuits, but if there are any , they must be constant and accounted for in the analysis. Measurements for each fixture type are averaged to determine fixture demand. For new lighting equipment, measurements should be made after at least 100 hours of use.

For smaller projects, measuring the fixture powers before and after the retrofit may not be practical. In these cases, it is important to focus measurements on the most uncertain parameters. In lighting projects, the existing stock of lighting equipment tends to be the least well-known item, as various equipment types may have been installed over time. The newly installed lighting equipment will be specified, and is typically much more predictable. Where measurements are not practical, fixture powers can be estimated from a table of standard fixtures, such as those used in utility programs. While this approach may be acceptable on some ESPC projects, it is not IPMVP-compliant. A conservative approach is to establish baseline fixture wattages on current minimum efficiency standards.

11.1.4 Interactive Effects

For spaces that are heated and cooled, there will be interactions between the lighting equipment and HVAC systems. A lighting retrofit will decrease cooling loads in the summer and increase heating loads in the winter. The general approach to dealing with interactive effects is presented in Section 7.3.

Methodologies for determining some of the more common interactions, such as lighting and HVAC, have been developed.[45] These effects are sometimes ignored, however, because the cooling bonus and the heating penalty can somewhat cancel each other. Projects implemented in extreme climates may wish to quantify these interactive effects, as they may be significant. If these effects are to be ignored, this provision should be included in the contract and agreed to by both parties.

11.1.5 Savings Calculations

The equations used for calculating energy and demand savings for lighting efficiency projects are shown below. These equations do not include any interactive effects.

Equation 11-1: Total Energy Savings

$$kWh\quad Savings_{Total} = (kWh\quad Savings_1) + (kWh\quad Savings_2) + ... + (kWh\quad Savings_n)$$

[45] See Rundquist, et. al., *Calculating Lighting and HVAC Interactions,* ASHRAE Journal, November 1993, or Sezgen, Osman et. al., *Interactions Between Lighting and Space Conditioning Energy Use in Commercial Buildings*, LBNL-39795, April 1998.

Equation 11-2: Total Demand Savings

$$kW \quad Savings_{Total} = (kW \quad Savings_1) + (kW \quad Savings_2) + ... + (kW \quad Savings_n)$$

As shown above, the total energy and demand savings will be the sum of the savings from each usage group or piece of equipment, 1 through n. The energy and demand savings for each usage group should be calculated separately, as shown in Equation 11-3 and Equation 11-4. One should keep in mind that the usage groups assigned to determine fixture powers may be different from those used to measure operating hours, and the equations must be carefully applied.

Equation 11-3: Energy Savings for Each Usage Group or Piece of Equipment

$$kWh \quad Savings = (kW_{Baseline} \times Hours_{Baseline}) - (kW_{Post} \times Hours_{Post})$$

Equation 11-4: Demand Savings for Each Lighting Usage Group or Piece of Equipment

$$kW \quad Savings = \{(kW_{Baseline}) - (kW_{Post})\} \times (Diversity \quad Factor)$$

where:

kWh Savings =	Kilowatt-hour savings realized during the performance period time period
kW Savings =	Demand savings realized during the performance period time period, typically calculated for each month or utility billing period
$kW_{baseline}$ =	Total baseline demand for a usage group or piece of equipment (1 through n)
kW_{post} =	Total performance period demand for a usage group or piece of equipment (1 through n)
Hours =	Number of operating hours during the performance period time period for the usage group or piece of equipment (1 through n)
Diversity Factor=	Percentage of lighting load on during the building's peak demand for the usage group or piece of equipment (1 through n)

11.1.6 Ongoing Verification

Using an Option A approach for lighting retrofits typically precludes the need for savings adjustments, except for non-routine adjustments (see Section 7.2). Since the connected load and run-times of each fixture should not change over time, additional measurements during the performance period are typically not warranted.

It is important however, to periodically verify the retrofit's potential to perform. This means that equipment types, quantities, and condition are verified. Often, a different portion of the installation is inspected each year to verify that the proper equipment has been installed and is operating as expected. Lighting levels may be spot-checked, and specifications of replacement lighting equipment kept on site may be verified. In order to ensure overall performance, some sites may need to specify a maximum allowable number of burn-outs in the performance period.

11.2 LIGHTING CONTROLS

A common energy conservation measure is lighting controls. The source of savings in these lighting controls projects is reduced energy use due to decreased run-times (or reduced load factor if dual switching or dimming is employed) of the lighting equipment due to day-lighting or occupancy controls.

Key issues related to lighting controls projects include:

- Ascertaining existing equipment inventory
- Establishing equipment performance
- Determining baseline operating hours
- Determining performance period operating hours

Several of the issues pertaining to lighting controls are the same as for lighting retrofits. Specifically, establishing equipment inventories and determining fixture energy use are the same as lighting retrofits (discussed in section A.1). In lighting controls projects, baseline and performance period fixture powers are assumed to be the same since they are unaffected by the retrofit.

Baseline and performance period operating hours can usually be accurately predicted using short-term measurements. For this reason, energy savings can often be determined and verified using an Option A approach. An Option B approach that includes ongoing measurements of operating hours throughout the term of the contract may be warranted in some cases. When using Option A, additional annual verification activities are needed to account for the possibility of changes in the controls during the performance period.

11.2.1 Operating Hours

Operating hours are the key performance parameter in lighting controls projects, and should be measured before and after retrofit to quantify change in operating hours. The statistical sampling and measurement strategies described for lighting efficiency projects can also apply to lighting control projects to determine operating hours. The primary difference in the methodology is the measurements that must be conducted both before and after the retrofit.

11.2.2 Equipment Performance

Although fixture demand is not expected to change, it is an important parameter used in the savings calculations. Accurately estimating the electrical demand (kW) from the various fixture types is critical for savings estimates to be valid. In best practice applications, the fixture powers are measured. Sampling strategies outlined for operating hours for lighting efficiency projects should also be applied to fixture powers. Typically, these measurements are made in the baseline period. In some cases, fixture wattages may be based on current lighting efficiency standards, which can be a conservative method as it ensures the baseline energy use is not overstated.

11.2.3 Savings Calculations

The equations used for calculating energy savings from lighting controls projects are the same as those for lighting efficiency projects shown in Equation 11-1 through Equation 11-4. These equations, however, can be simplified mathematically if the baseline and performance period demand are the same. The total energy savings will be the sum of the savings from each usage group or piece of equipment.

There is typically no demand savings associated with lighting control projects. Performance period demand is the same as baseline demand unless reduced operation coincidence with building peak demand is demonstrated. Interactive effects between the lighting and HVAC systems should be accounted for as described for lighting efficiency projects above.

If controls are implemented in conjunction with a lighting retrofit, the baseline demand should be based on the post-retrofit equipment. Using a single savings equation to calculate either energy or demand savings (such as Equation 11-3) for both retrofits can ensure that savings are not double-counted. Demand and energy savings require separate calculations.

11.2.4 Ongoing Verification

It is necessary to periodically verify the retrofit's potential to perform. As is the case with lighting efficiency projects, equipment types, quantities, and the condition of the controls equipment should be verified. Control set points must also be checked. It is common practice to have a different portion of the installation inspected each year to verify that proper equipment has been installed and is operating as expected. The performance of the controls should be verified through field testing. For occupancy controls, sensitivity and delay time should be checked. For day-lighting controls, illumination threshold set points should be verified to ensure proper operation. Some manufacturers may have recommended testing procedures.

11.3 CONSTANT-SPEED MOTORS

One of the most common energy conservation measures is motor efficiency improvements resulting from motor replacements serving constant loads. The source of savings in these projects is reduced demand and energy use due to higher efficiency motors.

Key considerations related to motor efficiency projects include:

- Ascertaining existing equipment inventory
- Establishing baseline equipment performance
- Determining performance of new equipment
- Determining operating hours

The issues pertaining to motor replacement projects are relatively simple, and energy savings can be accurately predicted using short-term measurements. Therefore, energy savings from constant-load motors are normally determined and verified using an Option A approach.

11.3.1 Equipment Inventory

Equipment inventories are typically provided on a room-by-room or system-by-system basis. Survey data that should be collected for the baseline and after installation and should include the motor application, location, loads served, operating schedule, and nameplate data. Nameplate data collected for each motor should include the motor tag or other identifier, manufacturer, enclosure type, horsepower, service voltage, nominal efficiency, and rated motor speed. Additional nameplate data can be helpful, and should be recorded, as shown in Table 11-1.

The party responsible for defining the baseline will also identify any non-operating motors, and adjust the baseline accordingly.

Table 11-1 Example Motor Survey Data Form[46]

Item	Baseline	Post-Installation
Survey completed by		
Motor ID or Tag #		
Application		
Manufacturer		
Model Number		
Enclosure or Frame Type		
Horsepower (hp)		
Rated Motor Speed (rpm)		
Voltage		
Phase and Frequency (Hz)		
Full Load Amps		
Service Factor		
Power Factor		
Insulation Class		
Serial Number		
Duty Rating		
Design Code Letter or Locked Rotor Amps		
Weekday Operating Hours		
Weekend Operating Hours		
Physical and Environmental Conditions		

11.3.2 Equipment Performance

In motor efficiency projects, the key performance factor is motor power. Best practice requires that both the baseline and post-installation motor powers are measured. When measuring motor power, true root-mean-squared power measurements should be used, and/or current, volts, and power factor should be measured to calculate demand. Motor speed, measured in revolutions per minute (RPM), should be recorded based on spot metering of each motor to be replaced. Power meters with accuracy at or approaching ±2% of readings should be used. The same meter and measurement procedures should be used in both the baseline and performance period scenarios.

The power draw of a motor depends upon its load factor, which can be determined only through measurements. A load factor is the ratio of the load actually drawn compared with what could be drawn under full-load conditions. In addition to impacting the power required, load factor also affects both the power factor and efficiency of a motor. For most motors, efficiency varies based on load factor, with the efficiency peaking at about 75% load and decreasing substantially under 50% load[47]. Similarly, overloaded motors experience decreased efficiency. Since load factors and corresponding motor power can vary substantially, it is important to measure rather than estimate the load on motors. This is why replacing undersized or oversized motors with correctly sized motors can be an effective energy conservation measure.

[46] A user-friendly data collection form for motors is included in Determining Electric Motor Load and Efficiency, US DOE Motor Challenge Fact Sheet, available at www1.eere.energy.gov/industry/bestpractices/pdfs/10097517.pdf

[47] Determining Electric Motor Load and Efficiency, US DOE Motor Challenge Fact Sheet, available at www1.eere.energy.gov/industry/bestpractices/pdfs/10097517.pdf

In projects where many motors on similar applications are being replaced, a sampling strategy can be appropriate to determine performance parameters. The appropriate use of statistically valid samples is discussed in Section 7.4.4 and in Appendix B.

For certain applications, such as motors located in a conditioned air stream, additional measurements may be needed to capture interactive effects produced by the heat of the motor. In these cases, temperature measurements of the working fluid may be taken on either side of the motor and documented so the baseline and performance period measurement locations are identical. These measurements, however, may be impractical since the temperature difference may be small and could be determined only by a very accurate meter. As an alternative, ASHRAE presents a simplified method for estimating the heat gain form motors in a conditioned air-stream[48]. Estimating these interactive effects using other methods (such as whole-building modeling) may be appropriate.

11.3.2.1 Verify Constant Loading

When categorizing motors as constant-load devices, performance measurements should be made over a period of time. The period of time required to confirm constant loading varies depending on the application. Confirming that a motor operates under constant-load conditions is easily accomplished if measurements made to determine run-times use an ammeter or power meter rather than a device that determines only if a motor is on or off.

To verify that a load is constant, one compares the average of the measured values with all hourly non-zero values. An application may be considered constant if 90% of all non-zero observations are within ±10% of the average amperage or power. If any application cannot be verified for constant load, the data should be analyzed to determine whether the load for the motor varies systematically and predictably, whether the constant load was changed during the test period, or whether there is some system anomaly. If the load varies systematically, the motor is treated as a variable load. If a system anomaly occurs or the load changes during the short-term monitoring period, spot-metering and short-term monitoring tests should be repeated. In some cases it is appropriate to select a conservative load factor to simplify M&V even if the load is not truly constant. Each constant-speed motor application should be supported by schematic system drawings and control sequences. Once a load has been confirmed constant, additional verification should not be necessary.

11.3.2.2 Accounting for Motor Slip

For induction motors, the synchronous (unloaded) speed of a motor is greater than the actual speed of a loaded motor. The difference between the actual and rated (unloaded) speeds is called slip. The slip is a characteristic of a particular motor and describes how much the motor slows down as it gets loaded. Because the slip characteristics of pre and post retrofit motors with the same synchronous speed may be different, standard-efficiency motors and high-efficiency motors may rotate at different rates when serving the same load. Such differences in rotational speed may increase the amount of work done, and result in smaller savings than expected.

[48] ASHRAE Fundamentals Handbook 2005, Section 30 - Nonresidential Cooling and Heating Load Calculations.

Differences in either the measured load factor or rotation speed (rpm) between the existing motor and a new high-efficiency motor can impact savings. Changes in load factor or speed of more than 10% may occur if the new motor is smaller than the baseline motor. If the load factor or speed lies outside the expected range, the ESCO should provide an explanation, with supporting calculations and documentation. Large differences in load factor between the existing motor and the replacement high-efficiency motor point to operational problems or misunderstanding of the installation.

For motors where it is determined that end-use has not changed, the baseline and post-installation motor speed should be the same. For belt-driven motors, re-sheaving the motor can be an effective way to equalize system performance for changes in motor slip.

11.3.3 Operating Hours

On motor efficiency projects, baseline and performance period operating hours are assumed to be the same if they are unaffected by the retrofit. The operating hours are a major component in calculating the savings, however, and need to be accurately estimated. The most common approach is to measure the operating hours on all or a sample of motors with short-term or long-term monitoring during the baseline period and stipulate the operating hours in the contract. Monitoring should provide an estimate of annual equipment operating hours, and must be of sufficient duration to capture all operating conditions. For projects where post-installation operating hours will be different, post-installation measurements should be included.

On projects where many motors with similar operating patterns are being replaced, sampling strategies can be an appropriate way to ascertain operating hours. Examples of such motor groupings are supply fan motors, exhaust fan motors, and boiler circulating pump motors. Each group type should have similar use patterns and comparable average operating hours. The appropriate use of statistically valid samples is discussed in Section 7.4.4 and in Appendix B.

When measurements of operating hours are not supported by the project value, operating hours can be determined from schedules used in energy management systems, operational logs, or documented operating schedules provided by the federal agency. Operating hours can be estimated for each individual motor or for groups of motors with similar applications and schedules.

11.3.4 Savings Calculations

The overall equations used for calculating energy and demand savings are Equation 11-1 and Equation 11-2, the same basic equations used for lighting efficiency projects. The total energy and demand savings will be the sum of the savings from each usage group or piece of equipment. Similarly, Equation 11-3 can be applied to determine the energy savings from each piece of equipment for each operating scenario.

Demand savings from motor efficiency improvements accrue <u>only</u> if the motors operating hours coincide with the building’s utility peak demand. In some cases, only a subset of the motors installed may contribute to demand savings. The demand savings are calculated from the time period in which the minimum demand savings are achieved during the building’s utility peak period. Operating schedules should be closely considered to ensure that only the motors that are operating during the building's peak hours are included in calculating demand savings using Equation 11-5, below. Adjustments to the baseline demand may be required for non-operating motors that are normally operating or intended for operation.

Equation 11-5: Peak Demand Savings for Each Usage Group or Piece of Equipment

$$kW \quad Savings = Minimum\{(kW_{Baseline}) - (kW_{Post})\}_{t-peak}$$

where:

kW Savings =	Peak demand savings realized at the utility meter during the performance period peak time period t-peak, typically calculated for each month or utility billing period
kW_{post} =	Performance period demand for motor or usage group during time interval t-peak
$kW_{baseline}$ =	Baseline demand predicted for motor or usage group (1 through n) during same time interval

11.4 VARIABLE-SPEED MOTORS

Variable-speed-drive (VSD) efficiency projects involve the replacement of existing motor or load controllers with VSD motor controllers. These projects reduce demand and energy use, but do not necessarily reduce utility demand charges. VSD retrofits often include the installation of new, high-efficiency motors. Typical VSD applications include HVAC fans as well as boiler and chiller circulating pumps.

Key considerations related to variable speed motor projects include:

- Ascertaining existing equipment inventory
- Establishing baseline equipment performance for each operating scenario
- Determining operating hours for each operating scenario
- Determining performance of new equipment for each operating scenario

Many of the issues pertaining to variable-speed motors are the same as for constant-speed motor replacements. There are, however, some additional considerations. Establishing equipment inventories and determining baseline equipment performance for variable-speed motors are the same as for constant-speed motors, which are discussed in the previous section. In addition to the equipment inventory items identified for constant-speed motors, surveys should also document the baseline motor controls (e.g., motor starters, inlet vane dampers, and VSDs).

11.4.1 Establish Baseline Equipment Performance and Operating Hours

For projects whose baseline loads are constant, as described in Section 11.3.2, the baseline demand should be established by following the procedures outlined in Section 11.1.3 above. For projects where loads are not constant, additional short-term metering is required during the baseline. Metering should be performed on all baseline motors or on a randomly selected sample of motors with the same application and/or operating hours.

For applications where the baseline is variable, short-term measurements of electrical demand are required. The length of metering should capture all normal operating scenarios, and the baseline power usages should correspond to specific operating scenarios or to other independent variables.

Demand metering should be of sufficient duration to determine operating hours for each different motor operating scenario. For systems where variations are predictable, shorter term monitoring may be sufficient. Sometimes, spot measurements made while the motors' applicable systems are modulated over their normal operating range (i.e., measure pump motor demand in cooling mode, economizer mode, and heating mode) are adequate.

Short-term monitoring for variable-load, baseline motors should be done to characterize baseline usage. Two approaches to evaluating baseline energy use are as follows:

- Develop a schedule of motor kW, e.g., 4,380 hours per year at 40 kW and 4,380 hours per year at 20 kW
- Define the relationship between motor kW and the appropriate independent variables, such as outdoor air temperature or system pressure for a variable air-volume system

11.4.2 Post-Installation Performance

After VSDs are installed, short-term or long-term metering should be conducted on all motors or a statistical sample of similar motors if appropriate. Post-installation metering is intended to determine the actual operation of the VSDs, including:

- Power used by new equipment in each operating scenario, or as a function of a measurable variable(s).
- The hours of operation for each operating scenario

The performance period performance of the new equipment can be predicted prior to implementation, but must be confirmed. This is especially a concern for VSD projects that claim demand savings, as VSDs can go to 100% speed under full-load conditions, eliminating any peak demand savings. Ongoing measurements are required for applications that are not easily predictable, such as HVAC uses.

The duration of the performance period metering will depend upon the predictability of the performance of the new equipment. At a minimum, the metering should capture all normal operating scenarios. For many applications, continuous metering for at least the first year of the performance period will be required to confirm operations under all conditions.

Measuring demand or a direct proxy such as the speed of the drive, captures the performance and operating hours of the system. The power draw of the motors with VSDs will vary depending on the speed of the motor being controlled and the efficiency of the VSD. Although many VSDs display motor power, these readings must be verified before they can be deemed reliable. A calibrated power meter should be used to correlate VSD speed with actual kW. Direct motor rpm measurements can be made or readings can be read from the VSD control panel. Accurately correlating motor demand (kW) to the motor speed allows the rpm's to be tracked and act as a proxy for demand. In addition, other factors, such as downstream pressure controls, can affect the power draw and may need to be considered. If routine adjustments are planned, the appropriate independent variables should also be measured so they may be correlated with the performance period demand readings.

For systems whose variations are predictable and level of savings is too low to warrant the cost of long-term measurements, short-term monitoring may be utilized. Spot measurements made while the motors' applicable systems are modulated over their normal operating range can be used to validate savings estimates.

11.4.3 Savings Calculations

The overall equations used for calculating energy and demand savings from VSD projects are Equation 11-1 and Equation 11-2, the same basic equations used for lighting efficiency projects, which are restated here as Equation 11-6 and Equation 11-7. The total energy and demand savings will be the sum of the savings from each usage group or piece of equipment (1 through n).

Equation 11-6: Total Energy Savings

$$kWh\quad Savings_{Total} = (kWh\quad Savings_1) + (kWh\quad Savings_2) + ... + (kWh\quad Savings_n)$$

Equation 11-7: Total Demand Savings

$$kW\quad Savings_{Total} = (kW\quad Savings_1) + (kW\quad Savings_2) + ... + (kW\quad Savings_n)$$

In order to determine the savings from each piece of equipment, the baseline (and performance period) energy must first be determined using Equation 11-8. The energy use will be the sum of the energy used in each operating scenario (denoted as a through z). If demand (kW) is a function of an independent variable (such as speed), then the demand at each value of the independent variable must first be calculated.

Equation 11-8: Baseline (or Performance period) Energy Used by Each Usage Group or Piece of Equipment

$$kWh_{Baseline,1} = (kW_{Baseline,a} \times Hours_{Baseline,a}) + (kW_{Baseline,b} \times Hours_{Baseline,b}) + ... + (kW_z \times Hours_{Baseline,z})$$

The savings from each piece of equipment (1 though n) can then be determined using Equation 11-9. These values are then summed, as shown in Equation 11-6, to determine total energy savings.

Equation 11-9: Energy Savings for Each Piece of Equipment

$$kWh\quad Savings_1 = kWh_{baseline,1} - kWh_{post,1}$$

Where:

$kW_{Baseline}$	=	Baseline demand for a usage group or piece of equipment (1 through n)
kW_{Post}	=	Performance period demand for a usage group or piece of equipment under the same operating conditions as the baseline (1 through n)
kWh_{Post}	=	Energy required by the new motor encountered for interval t in the performance period (1 through n)
$kWh_{Baseline}$	=	Energy that the baseline motor would have used under the under the same conditions encountered for the same interval t in the performance period (1

through n)

$Hours_{Post}$ = Number of operating hours during the performance time period for a specific group or piece of equipment

$Hours_{Baseline}$ = Number of operating hours during the baseline time period for a specific group or piece of equipment

Demand savings from VSD projects accrue only if the VSD does not operate at 100% speed during the hours that are coincide with the building's utility peak demand. The level of demand savings achieved is calculated from the time interval in which the minimum demand savings are achieved during the building's utility peak period. For this reason, it is important that the measurement interval of the post installation conditions accommodate the utility's actual billing interval. The demand savings achieved by many VSD projects are diminished during peak cooling loads.

As shown in Equation 11-10, demand savings are based on the kW measured before new motors are installed minus the kW measured after the new motors are installed the same interval during the building's peak period when the minimum demand savings are achieved.

Equation 11-10: Peak Demand Savings

$$kW \quad Savings = Minimum\{(kW_{Baseline}) - (kW_{Post})\}_{t-peak}$$

where:

Time period (t-peak) is defined as the time interval during the building's peak period for that billing month during which the minimum demand savings are achieved. Billing months are defined by the serving electric utility.

kW Savings = Peak demand savings realized at the utility meter during the performance period peak time period t-peak, typically calculated for each month or utility billing period

$kW_{baseline}$ = Baseline demand for motor or usage group predicted during time t

kW_{post} = Performance demand for motor or usage group during the same interval

11.4.4 Ongoing Verification

As is the case in other projects, it is necessary to periodically verify the retrofit's potential to perform by verifying equipment types, quantities, and condition of the equipment. If the VSD is continuously monitored, data should be inspected periodically to ensure that the VSDs are still working properly. Since VSDs can easily be overridden in the field, the performance of each VSD should be verified.

11.5 CHILLERS

A common energy conservation measure is chiller replacement projects. The source of savings on these projects is reduced chiller demand and energy use due to higher efficiency equipment.

Key considerations related to chiller efficiency projects include:

- Establishing existing equipment performance and plant operating conditions
- Determining cooling loads and chiller sizing
- Confirming performance of new equipment

The issues pertaining to chiller replacement projects tend to be relatively complex and require short- or long-term measurements. For these reasons, energy savings are typically determined and verified using an Option B approach. The recommended approach is described below and is detailed in the Standard M&V Plan for Chiller Replacements, which is included as Appendix K.

11.5.1 Baseline M&V Activities

The baseline M&V activities for a chiller replacement project are intended to:

- Define the existing chillers' efficiencies (i.e., kW/ton)
- Determine the cooling loads experienced by the plant based on outdoor air temperatures and other variables as needed
- Determine key operating conditions of the chiller plant (e.g., condenser water supply temperatures, chilled water supply temperatures, chiller sequencing).

The first step in establishing a baseline is to document the existing conditions. The information needed includes nameplate data, seasonal operating schedules, chiller ages and condition, loads served, locations, condition of peripheral equipment, and month and time of day of peak building demand.

Short-term measurements are required to determine baseline conditions across the expected range of operating conditions (e.g., load, outside air temperature and humidity), and the metering period should include both shoulder and peak months. Parameters that should be measured include:

- Chiller electric demand (kW) and energy use (kWh)
- Chilled water load (e.g., tons), calculated from coincident measurements of chilled water flow (gpm), chilled water supply, and return temperatures (ºF)
- Condenser water supply and return temperatures (ºF)
- Pump and cooling tower demand (kW) and energy use (kWh) (if affected)
- Outdoor air temperature and humidity

For a chiller project, the most important measurements are the chilled water temperatures, which are used to calculate cooling loads and equipment efficiencies. The sensors used for baseline and performance measurements should meet minimum accuracy requirements and must be properly calibrated. A minimum accuracy of ±0.3°F is recommended, and identical sensors for supply and return are preferred. If the accuracy of any instrument is less than prescribed, the measurements may not be suitable, as they will introduce unacceptable levels of error into the energy calculations. Examples of the error introduced by these sensors are given in Section 5.4.1.

Baseline measured data are used to determine existing load profiles. Correlating the measured loads with independent variables such as outdoor air temperature will allow the load profile to be adjusted to typical conditions, which is often appropriate. To account for interactions (reductions in load) from other measures, these reductions in load should be estimated and the load profile should be adjusted accordingly.

Metered data should also be used to calculate existing chiller performance (kW/ton), which varies with operating conditions (e.g., load, chilled water temperature, and condenser water temperature). In addition, the metered data are used to determine the key operating conditions of the chiller plant, such as cooling tower performance, chilled and condenser water set points, chiller sequencing, and other baseline parameters, all of which should be thoroughly documented.

11.5.2 Post-Installation Performance

After the new chillers have been installed, short-term or long-term metering should be conducted to determine the actual operating efficiencies of the chillers and any affected equipment. The post-installation performance of the new equipment can be predicted, and may also be factory-tested, but should be confirmed after installation. The power use of any peripheral equipment that was affected, such as pumps and cooling towers, should also be measured.

Typically, permanent metering equipment is installed with the new chillers. The accuracy and calibration of all meters should be confirmed prior to data collection. Depending on the project, the metering can either be continuous or periodic. Continuous metering can accurately track operations and offers additional opportunities to improve overall performance of the chiller plant. The down-side of continuous metering is the challenge of keeping the data continuous and accurate.

One approach is to meter continuously for informational purposes, but calculate savings using periodic equipment performance tests. This approach lends itself to projects that have a well defined cooling load profile and the performance of the chillers themselves is the primary concern. Chiller projects, however, will often include controls or other measures that may require continuous monitoring.

Parameters typically measured include:

- Chiller electric demand (kW) and energy use (kWh)
- Chilled water load (tons), calculated from coincident measurements of chilled water flow (gpm), chilled water supply, and return temperatures (ºF)
- Condenser water supply and return temperatures (ºF)
- Pumps and cooling tower fans (if affected) demand (kW) and energy use (kWh)
- Outdoor air temperature and humidity

Data collected can be used to calculate chiller performance (kW/ton) and actual cooling loads. These data should be used to calculate savings or at least compared with the expected values to ensure continued performance. Periodically repeating these tests is recommended, and this also requires recalibration of instrumentation.

11.5.3 Savings Calculations

The overall equations used for calculating energy and demand savings from chiller replacement projects are Equation 11-1 and Equation 11-2, the same basic equations used for lighting efficiency projects. The total energy and demand savings will be the sum of the savings from each piece of equipment.

Equation 11-8 can be applied to determine the energy savings from each piece of equipment, although it may need to be applied for a number of operating scenarios. Another way to state this equation, which is more suitable to hourly calculations, is shown in Equation 11-11.

Equation 11-11: Energy Savings for Each Piece of Equipment

$$Energy \quad Savings(kWh) = \sum_t (kWh_{Baseline} - kWh_{Post})_t$$

Where:

$kWh_{Post,\,t}$	=	Energy required by the new chiller encountered for interval t in the performance period
$kWh_{Baseline,\,t}$	=	Energy that the baseline chiller would have used under the under the same conditions encountered for the same interval t in the performance period

The utility peak demand savings from many chiller projects are established during peak cooling loads when demand savings are at their minimum. Demand savings resulting in cost reductions from chiller projects can occur only during the hours that are coincide with the building's utility peak demand. The level of demand savings achieved is calculated for the interval during this time period in which the minimum demand savings are achieved, which typically occurs under peak cooling conditions, and can be calculated using Equation 11-10. For this reason, the measurement interval used to measure the post installation conditions should accommodate the utility's actual billing interval.

11.6 WATER

Water conservation projects are often included on ESPC projects. The source of savings in these projects is reduced water use due to increased performance of the water using equipment, fixtures, or controls. Savings can also result from reduced water supply charges, sewer charges, and/or energy costs. Energy savings are commonly achieved from reduced water heating, and additional energy savings may be realized for facilities that use pumps to boost water pressure or to irrigate with groundwater, or at facilities with their own water treatment systems.

Key issues related to water conservation projects include:

- Ascertaining equipment inventory for both the baseline and post-installation
- Establishing existing equipment performance for each type of device
- Determining usage characteristics of each type of device
- Determining post-installation equipment performance for each type of device
- Accounting for interactive effects

Several of the issues pertaining to water retrofits are similar to those affecting lighting efficiency projects. There are, however, some differences in implementation procedures. Since the performance of many common water conservation projects can be accounted for through short-term measurements, and usage factors can be estimated, water savings are most often verified using Option A. All M&V options, however, can be applied to water projects.

There are several circumstances that would indicate that another M&V approach should be considered. Projects that save more than 15% of the total water usage at a single meter should use an Option C approach. When an Option C approach is used, the quality and accuracy of the water meters should be verified. If existing water meters are used, historic water meter data may not provide an accurate baseline, and additional meters should be installed. One difficulty using whole-building consumption data is that outdoor water use can be so variable that desegregating that end use from a facility's water load, which is also variable in use, can be problematic.

Option B may be warranted for projects where 1) the water consuming devices do not have constant flows; 2) operating schedules are erratic and require measurement; 3) sub-meters already exist or can easily be installed, such as individual buildings on a campus, cooling towers, irrigation, or gray water systems; or 4) metering costs are small in comparison to other project costs.

11.6.1 Typical Measures

A partial list of water conservation measures that federal agencies can consider includes the following:

- Replacing components of older plumbing systems with water-saving equipment such as ultra–low-flow toilets, waterless urinals, high-efficiency showerheads, aerators, and self-closing valves
- Eliminating continuously flowing urinals, lab drains, drinking fountains, and other similar devices
- Replacing once-through cooling devices for space cooling, ice making, and other purposes with closed-loop or air-cooled systems
- Improving technologies and management techniques for boilers, dishwashing, laundry, and other special purposes
- Maintaining proper pressure through the use of pressure regulating valves
- Decreasing the use of water for landscaping by installing drought-tolerant landscaping or implementing more efficient irrigation systems and practices
- Installing gray water, rainwater, and reclaimed water-recycling technology for flushing and/or irrigation

11.6.2 Equipment Inventory

Equipment inventories are typically provided on a room-by-room basis. Survey data that should be collected include the type of device/fixture, location, number in each location, and nameplate data. The inventory should characterize both existing and post-installation equipment, and should be updated after installation to ensure accuracy.

11.6.3 Equipment Performance

On water efficiency projects, the key performance factor is water consumption on a per use basis (i.e., gallons per flush). In best practice applications, both the baseline and performance period water consumption is measured. Sampling strategies for similar fixture types are appropriate, and confidence and precision of 80% and 20%, respectively, are recommended. Typically, spot measurement of flows is sufficient to characterize the performance of various fixture types.

The average flow rates for each type of fixture measured should be used. Flow rates may vary, depending on the specific equipment, water pressure, and condition of the fittings. Measurement strategies include making volumetric measurements or using a portable flow meter. Suitable flow meters should be selected for appropriate accuracy and should have flow ratings that conform to field conditions. Several flow measurement techniques are included in ASHRAE Guideline 14 Section A5.6. Spot measurements are useful, not only to quantify water consumption, but also to verify that all devices assigned to any sampling groups have similar performance characteristics.

ESCOs and agencies should exercise caution if they rely on nameplate data to determine water use. The water consumed by many water fixtures can be easily adjusted to go well above or below nameplate specification. Actual use for existing fixtures can be determined by short-term metering or other techniques. All newly installed equipment should be tested and adjusted as needed.

11.6.4 Usage Characteristics

On water efficiency projects, baseline and performance period use of the water consuming equipment (i.e., flushes per day) are assumed to be the same since they are unaffected by the retrofit. The frequency with which the equipment is used is a major factor in calculating the savings, however, and needs to be accurately estimated. The most common approach is to estimate the usage of fixtures and stipulate these operating characteristics in the contract. Projects quantifying outdoor water use using Option B or C methods would need to develop regression models based on parameters that drive water use, such as rainfall, so that routine adjustments can be made.

Once a complete inventory and performance characteristics of the fixtures have been determined, the number of uses per day must be determined. Since this parameter is not easy to measure, it is typically estimated. For many fixture types, the only usage item to quantify is the frequency of use. For others, such as showers and sinks, both the frequency and duration of use must be determined. The overall fixture usage is typically determined from published studies and historic data on the actual building’s occupancy. Because of the differences in performance of toilets and urinals, the daily per fixture use is often segregated by men and women.

Units of measure should be consistent with the fixture type, but all should be expressed in a common volumetric measure (usually gallons) so that those totals can be aggregated easily. For example, water consumption for water closets might be expressed in gallons per flush, while showers consumption might be expressed in gallons per minute. Water consumption per unit of measure must then be quantified in the same units, and periods of service must be expressed in consistent terms (such as flushes per day, or minutes per shower and showers per day). In facilities where the usage changes seasonally (e.g., a school summer vacation period), separate data will be needed for each season.

Once the fixture inventory, performance characteristics, and usage parameters have been estimated, the data should be compared to historic water consumption at the facility to ensure that the consumption and savings values are reasonable.

11.6.5 Ongoing Verification

Using an Option A approach for water retrofits typically precludes the need for savings adjustments, except for non-routine adjustments (see Section 7.2). Since the performance of each fixture or end use should not change over time, and usage parameters are typically stipulated in the contract, additional measurements during the performance period are not warranted.

It is important, however, to periodically verify the retrofit's potential to perform. This means equipment types, quantities, and condition of the installed equipment have to be verified. Often, a different portion of the installation is inspected each year to verify that the proper equipment has been installed and is operating as expected. Confirming the type of equipment replacement stock that may be kept on site is also advisable.

11.6.6 Other Issues

There are several additional issues that should be considered when implementing water conservation projects. Some of these issues are outlined below.

- Some water measures may actually increase energy use, such as switching from a once-through cooling system to a closed-loop cooling system. It is important that these energy impacts are quantified.
- Water conservation measures may reduce the energy used for water heating, the level of which will depend upon the efficiency of the existing water heater.
- Water utilities can have demand charges based on the size of the utility meter. Typically, the meter would have to be downsized to realize demand cost savings.
- Water and sewer rates vary considerably, and the actual rate structure should be applied. For locations that do not charge on the basis of consumption for water or sewer, water cost savings will be more difficult to generate. Most areas, however, bill for water and sewer service from meter readings, and a large percentage of charges are consumption-based.
- When evaluating outdoor water use that is not sub-metered, the usual first step is to evaluate several years of water consumption data to compare seasonal irrigation use with non-seasonal irrigation use. The difference can be used for a baseline, but should be adjusted for changes in temperature, rainfall, evapotranspiration, and/or other relevant factors, if possible. If the water utility separately meters outdoor water use, then establishing baseline use is relatively simple, except for concerns regarding the accuracy of older utility meters.
- Irrigation technologies increase the delivery efficiency of the water (e.g., drip irrigation or more efficient sprinkler technologies) or include other changes that result in lower evaporative losses. The savings from these retrofits depend on local climate and evapotranspiration rate as well as plant species.
- Most domestic water use is for cleaning and transporting waste. These are sanitary functions that employ equipment and systems designed to comply with carefully crafted sanitary codes and standards. Saving water by using methods that compromise system performance is unacceptable.

11.7 GEOTHERMAL HEAT PUMPS

In general, geothermal heat pump (GHP) projects face the same issues as any HVAC system replacement, but with some additional items related to system specific features. Geothermal heat pumps, sometimes called ground source heat pumps, are categorized as either closed- or open-loop systems. The most typical retrofit involving GHP systems at federal sites involves replacing customary HVAC systems with GHP systems using vertical-bore ground heat exchangers, and this discussion focuses specifically on that system type.

For closed-loop systems, heat pumps absorb heat from and reject heat to a piping loop that contains water or water/antifreeze solution. The loop includes a borefield consisting of an array of pipes buried in the ground. The borefield acts as a heat exchanger, absorbing heat from and rejecting heat to the solution.

Key issues related GHP projects include:

- Ascertaining heating and cooling loads
- Establishing baseline equipment efficiencies
- Predicting performance of the GHP systems
- Verifying the performance of the installed GHP system

The last two issues listed above involve challenges that are unique to GHP projects, and are discussed below. Estimating the energy use of such equipment is difficult because both the cooling efficiency (EER) and the heating effectiveness (COP) of the heat pumps depend on the temperature of the fluid received from the ground heat exchanger. This fluid temperature, in turn, depends on the property of the soil formation at the site, and on the building heating and cooling loads.

For this reason, energy savings from GHP retrofit projects are usually estimated using an Option D approach. As-built drawings, on-site measurements, and models of the existing HVAC equipment are used to develop a baseline simulation model of the building using a building energy analysis programs such as DOE-2, TRACE 700, TRNSYS, or another program that includes subcomponent models for geothermal heat pumps and vertical-bore heat exchanger arrays.

As discussed in Section 4.5, outputs from the model are compared with site-monitored building energy use data (utility bills or temporary metering) to ensure adequate calibration. Once the model has been deemed to be of sufficient accuracy, it is typically driven with typical meteorological year (TMY) weather for the site to determine the average baseline annual energy use. The baseline models of the existing HVAC equipment are then updated with GHP models that match the rated performance of the equipment to be installed. A borefield model is also included. Defining parameters include soil formation thermal conductivity and deep-earth temperature (which are measured at the site using an *in situ* test), borehole depth, pipe dimensions, and the thermal properties of any grouting material. The system model is driven by TMY weather to estimate average post-retrofit annual energy use. The proposed energy savings are then the difference between the post-retrofit and the baseline annual energy use.

Since the savings estimates depend on the manufacturer's rated performance of the new GHPs, the recommended M&V approach calls for annual verification of the performance of the new systems. The two performance areas that should be verified are: 1) equipment efficiency and system performance; and 2) borefield performance.

11.7.1 Equipment Efficiency and System Performance

For sites with multiple installations, measurements can be made on a portion of the GHPs installed each year to ensure that they are still meeting the specified performance and the resulting guaranteed savings. If for example, the agency selects a random sample of 20% of the heat pumps that were installed, then all units will be verified every 5 years.

Since ground source heat pumps provide both heating and cooling, the efficiency of the dominant function should be tested. For a cooling dominated facility, during a specified period in peak cooling season such as July of each year (this could be in January at a heating-dominated site) data are collected from selected heat pumps. The following data should be collected at 5-minute intervals:

- Water temperatures entering and leaving the heat pump
- Ambient outdoor air temperature,
- Supply and return dry-bulb air temperatures for water-to-air GHP units; supply and return load water temperatures for water-to-water GHP systems
- Heat pump unit input kW

The measured input kW readings are compared with manufacturer's performance data for the same operating conditions (rated gpm, rated cubic feet per minute, entering water temperature, leaving water temperature). Since the manufacturer's data will be limited to full-load conditions, the data must be manipulated to eliminate part-load conditions and to avoid comparing part load conditions against full-load data. Once the data set has been selected, logged input demand (kW) readings are compared to manufacturer's performance published data at the given conditions.

If the overall average measured demand (kW) is less than 110% of manufacturer's published data, the modeled energy savings are considered to be true and accurate. If the average kW is greater than 110%, the energy savings are recalculated using the original building simulation model. The GHP performance profile is changed to reflect the sampled kW readings, and the model is rerun to determine the actual energy consumption and revised savings estimates.

In addition, heat pumps used in air distribution systems typically require a greater volume of air than conventional systems due to the more moderate supply temperatures. For retrofit applications, the distribution system may require modification to accommodate the increased volume of air required to heat and cool the facility. The overall ability of the system to adequately heat and cool the facility should be verified.

11.7.2 Borefield Performance

The long-term performance of a GHP system depends on the design of the vertical borefield, which acts as a heat exchanger between the ground and the fluid. System designers choose a design temperature for the fluid (usually around 95°F for cooling-dominated systems, around

40°F for heating-dominated systems) and use estimated peak load conditions to size the system. If the borefield is correctly designed, the temperature of the fluid supplied to the heat pumps from the borefield should only rarely exceed the design temperature in the cooling mode (or should rarely fall below it in the case of a heating-dominated system).

Because borefield performance may change over time, the performance of at least a sample of units should be verified each year. If measured data collected to verify equipment performance (water temperature entering the heat pump) are used, the percentage of readings in which the entering fluid temperature exceeded the design temperature should be determined. If more than 10% of the temperatures during full-load conditions exceeded the design temperature, it is likely that the borefield is undersized for the current building loads. Higher entering water temperatures in cooling mode (or lower temperatures in heating dominated systems) reduce system efficiency.

In such a situation it may be necessary to investigate whether building loads have changed since the project was installed (e.g., additional interior loads, increased operating hours). If it is ultimately determined that the loads have not changed, the ESCO may be required to adjust the model to account for the higher entering fluid temperatures, and to recalculate the savings accordingly.

11.8 RENEWABLE ENERGY PROJECTS

Federal agencies are allowed to use energy service performance contracts (ESPCs) for installation of renewable energy projects that reduce facility energy costs and related operation and maintenance expenses. The term "renewable energy" refers to sources of energy that are regenerated by nature and sustainable in supply.

Renewable energy projects covered by this section involve the installation of devices and/or systems that generate energy (e.g., electricity or heat) or displace energy use thorough the use of renewable energy resources. Examples of technologies include: photovoltaics (PV), active or passive solar systems for space conditioning or production of domestic hot water, biomass conversion systems (e.g., landfill gas methane recovery projects), and wind systems. For additional information on the measurement and verification of renewable energy projects, refer to IPMVP for renewables[49].

The most notable difference between renewable energy projects and other ECMs is that renewable projects supply energy rather than reduce the amount of energy used. Measuring the energy supplied allows for a simplified approach to measuring savings that is not possible with energy efficiency projects. Option B deserves special consideration when evaluating M&V options for renewable energy projects.

Like many projects, the performance of most renewable energy technologies depends on the environmental conditions, such as solar radiation or wind speed. The use of long-term averages of these values is reliable, but any M&V Plan should be structured in such a way as to allocate the risk due to short-term variations in environmental conditions. Therefore, it may be appropriate to stipulate these conditions and verify the performance of the equipment using

[49] International Performance Measurement & Verification Protocol: Concepts and Practices for Determining Energy Savings in Renewable Energy Technologies Applications, Volume II, August 2003.

short-term measurements (e.g., the efficiency of a solar hot water heater). Long-term performance typically needs to be verified.

11.8.1 Savings Calculations

There are two general approaches for calculating energy savings from renewable energy projects:

- Net energy use
- Normalized savings based on typical environmental conditions and actual performance characteristics

For all renewable energy projects, consideration should be given to the impact of parasitic energy use by the renewable system and to increased operations and maintenance costs due to the addition of new equipment. Demand savings from renewable energy technologies may occur, but, depending on the electric utility's rate structure, the energy must be available and uninterrupted during all peak periods. Accounting for demand savings requires more sophisticated metering that aligns measurement intervals with the utility interval.

11.8.1.1 Net Energy Use

The first approach involves directly measuring the energy output from the system and quantifying any additional costs incurred or savings realized. This approach is suitable for wind, PV, and other electricity generating equipment. The measurement concept assumes that energy (electrical and/or thermal) produced by the renewable system is used at the project site, and displaces energy that would have been provided by an existing source. Savings are determined by measuring the net amount of energy produced by the renewable system and used at the project site valued at prescribed utility rates. This approach eliminates the need for a baseline and places the risk of weather variations on the ESCO.

Utility savings from renewable measures that supply thermal energy (e.g., solar hot water heater) are determined by dividing the energy delivered by the efficiency of the original equipment (e.g., conventional water heater). For projects that may sell excess energy or store energy on-site, additional costs and savings may need to be considered. Cost savings using this approach can be calculated using Equation 11-12.

Equation 11-12: Cost Savings Determination Utilizing Net Energy Use Approach

$$CostSavings = (kWh \quad Delivered) \times (Rate_{kWh}) + \{\frac{(ThermalEnergy)}{EfficiencyDisplacedEquipment}\}$$

$$\times (\frac{1kWh}{3,413BTU}) \times (Rate_{kWh}) + \{\$_{EnergySold}\} - \{\$_{ParasiticLoads}\} - \{\$_{New \quad O\&MCosts}\}$$

Where:

kWh Delivered	=	Electrical energy delivered by the system and used at the facility
$Rate_{kWh}$	=	Specified cost of electrical energy
Thermal Energy	=	Thermal energy delivered by the system in Btu during the performance period
Efficiency Displaced Equipment	=	Operating efficiency of the equipment that would have been used
1kWh/3,414 Btu	=	Conversion between thermal energy (Btu) and electrical energy (kWh)

$\$_{Energy\ Sold}$	=	Funds received through the sale of energy produced
$\$_{Parasitic\ Loads}$	=	Cost of operating systems and equipment related to renewable technology
$\$_{New\ O\&M\ Costs}$	=	Additional cost of operations and maintenance due to renewable technology

11.8.1.2 Normalized Savings

The second primary approach involves calculating normalized savings based on typical environmental conditions and actual performance characteristics of the system. Savings are determined by calculating the difference between baseline energy and demand and predicted or metered energy and demand, with both sets of data adjusted to a prescribed set of conditions. Depending on the type of system, this strategy can use any of the four M&V options.

Normalizing savings in this manor places the risk of weather fluctuations on the federal agency, and requires that the ESCO periodically demonstrate that specified performance characteristics have been met. These performance characteristics and how they will be determined should be specified in the project-specific M&V Plan. Performance parameters that should be specified include efficiency of PV modules, minimum hot-water temperatures, and the content in landfill gases.

The basic energy savings equation (Equation 2-1) can be modified to determine cost savings, as shown in Equation 11-13.

Equation 11-13: General Savings Equation for Renewable Energy Projects

$$CostSavings = [\{(Baseline\quad Energy) - (Performance\ \ Period\quad Energy)$$
$$\pm Adjustments\} \times (Rate_{Energy})] - \{\$_{ParasiticLoads}\} - \{\$_{New\quad O\&M Costs}\}$$

Where:

Baseline Energy	=	The calculated or measured energy use of a piece of equipment prior to the implementation of the project
Performance Period Energy	=	The calculated or measured energy use of a piece of equipment after the implementation of the project
Adjustments	=	Routine and non-routine changes made to the baseline or performance period energy use to account for expected and unexpected variations in conditions
$Rate_{kWh}$	=	Specified cost of electrical energy
Thermal Energy	=	Thermal energy delivered by the system in Btu during the post-installation period
$\$_{Parasitic\ Loads}$	=	Cost of operating systems and equipment related to renewable technology
$\$_{New\ O\&M\ Costs}$	=	Additional cost of operations and maintenance due to renewable technology

11.8.2 Energy Metering

Determining the electrical output of systems is relatively straightforward. This is because electrical output and parasitic loads can be simply measured with many commercially available meters. Measuring thermal output (e.g., hot water from a domestic hot-water solar system displacing an electric water heating system) is also straightforward, but not necessarily inexpensive, using commercial Btu meters, water flow meters, temperature transducers, etc. However, all of the thermal and electrical output from a system does not necessarily displace an equivalent amount of load. This is due to storage, system losses, and differences in time between when useful energy is produced and when it is needed.

11.8.2.1 Electrical Metering

Electricity measurements associated with system output, parasitic loads, power to the project site, and power to third parties and the utility may be needed. All electrical meters (and related equipment) are usually provided, installed, owned, and maintained by the ESCO or the servicing utility.

When a net metering approach is used, meter(s) will typically show the measure's gross output (in kW and kWh) less parasitic use (e.g., pump motors) and sales to third parties or the local utility, as well as any local transformation and transmission and battery storage losses. The goal with this method is usually to measure net generation delivered to the project site. Metering, interconnection (including safety provisions), reporting, and other related issues are to be in accordance with current electrical standards and the requirements of the servicing electric utility.

With the net energy-use M&V approach, deliveries to and from the facility should be separately recorded and treated as separate transactions. For purposes of power delivered to the site, a single meter that records energy supplied to the site is preferred. If a calculated transformer loss value is used, it should be based on certified factory test data for that particular transformer.

The following are some suggested metering requirements:

- kWh and demand metering at the point of delivery
- Time of-delivery metering
- Provisions for remote meter reading

11.8.2.2 Thermal Metering

Thermal meters (e.g., Btu meters) are required for measuring the net thermal output of certain renewable energy systems (e.g., hot water generated by an active solar system). Note that metering of thermal energy requires a "net" measurement of flows and enthalpy to and from a system. Measurements of thermal flows may need to take into account any vented or wasted energy that is produced by the system but not used at the site, as well as distribution and storage losses. Also note that small errors in enthalpy measurements (usually determined by temperature) can introduce large errors in the energy calculations; hence, meter precision, accuracy, and calibration are especially important.

11.8.3 Notes on Some Renewable Energy Technologies

11.8.3.1 Active Solar Thermal Systems

Active solar thermal systems include systems for producing industrial process heat, domestic hot water, and space heating and cooling. Useful monitoring includes 1) site inspections and brief temperature and system monitoring for diagnostics, 2) spot, short-term, or long-term monitoring of system key parameters such as temperatures, energy flows, and control status, and 3) utility billing analyses.

11.8.3.2 Passive Solar Systems

Passive solar systems usually involve the performance of a whole building with architectural features such as overhang design and use of thermal mass. As such, this technology is different from other renewable energy measures in that mechanical devices with identifiable energy inputs and outputs are not involved. Thus, passive solar M&V typically involves the analysis of a whole building, and thus it is best to use utility billing analyses or calibrated simulation techniques, i.e., Options C or D.

11.8.3.3 Wind, PV, and Other Renewable Generation Projects

With these types of systems, the performance characteristics of the components are usually well defined, such as the conversion efficiency of the PV modules or the Btu content of landfill gas. In addition, the electrical or thermal flows can usually be easily measured and Option B is typically utilized. The complexity of these projects lies in projecting long-term performance due to variation in the resources (e.g., solar insolation, wind resource, or reserve of methane gas in a landfill) and accounting for any variations between when the resource is available and when it is needed (i.e., the interaction of storage systems and their inefficiencies).

11.9 NEW CONSTRUCTION

Performance contracting projects are not only applied to existing buildings, but are sometimes used to supplement the capital required for new-construction projects. The ESPC part of the project provides added budget for the implementation of energy saving features that would not have been otherwise included in the project. Financing for these items is provided by the ESCO, and the ongoing performance of the measures is guaranteed.

Examples of ESPC new-construction projects used to limit energy-related costs include improvements in the building’s glazing, lighting, heating and cooling, pumping, and air handling systems, as well as efficiency upgrades of other equipment that were originally planned for the building.

Savings from new-construction ESPCs are measured and verified using an Option D calibrated simulation approach, which is detailed in Section 4.5. The methodology detailed, however, is for projects conducted in existing buildings. One primary difference between the methods used for existing and new buildings is that for new construction the performance period model is calibrated and the baseline model is based on minimum code standards or the original building plans. The methodology followed for new construction projects is somewhat different and is detailed in IPMVP Volume III.[50]

[50] International Performance Measurements and Verification Protocol: Concepts and Options for Determining Energy Savings in New Construction, Volume III, April 2003.